SERVERS BOOKS No. 7

THE OBSERVER'S BOOK
ON

RADIO NAVIGATION

THE OBSERVER'S BOOKS

1 MAPS, CHARTS AND PROJECTIONS
by W. J. D. Allan and William Alexander

2 DEAD RECKONING NAVIGATION
by W. J. D. Allan and William Alexander

3 ASTRO-NAVIGATION—Part I
by Francis Chichester

4 ASTRO-NAVIGATION—Part II
by Francis Chichester

5 ASTRO-NAVIGATION—Part IV
by Francis Chichester

6 METEOROLOGY
by W. J. D. Allan and William Alexander

7 RADIO NAVIGATION
by W. J. D. Allan

8 AIRCRAFT INSTRUMENTS
by W. J. D. Allan

9 ASTRO-NAVIGATION—Part III
by Francis Chichester

10 PRACTICAL MATHEMATICS
by P. H. Robinson

11 PLANISPHERE OF AIR NAVIGATION STARS
by Francis Chichester

THE AIR CADET'S HANDBOOKS

1 NAVIGATION—Part I
by W. J. D. Allan

2 NAVIGATION—Part II
by W. J. D. Allan

3 HOW AN AEROPLANE FLIES
by C. G. Grey

4 HOW TO PILOT AN AEROPLANE
by N. Macmillan

5 ENGINE MECHANICS
by W. D. Arnot

THE OBSERVER'S BOOK

ON

RADIO NAVIGATION

BY

W. J. D. ALLAN

LONDON
GEORGE ALLEN & UNWIN LTD
MUSEUM STREET

FIRST PUBLISHED IN JUNE 1941
SECOND IMPRESSION JUNE 1941
THIRD IMPRESSION MARCH 1942
SECOND EDITION (FOURTH IMPRESSION) 1942

BOOK
PRODUCTION
WAR ECONOMY
STANDARD

THE PAPER AND BINDING OF THIS BOOK CONFORM TO THE AUTHORISED ECONOMY STANDARD

PRINTED IN GREAT BRITAIN
in 11-Point Baskerville Type
BY UNWIN BROTHERS LIMITED
WOKING

CONTENTS

INTRODUCTION

Radio Navigation is the most modern form of navigation, and the one in which there is most scope for development.

The older forms, such as map-reading, dead-reckoning, and astronomical navigation, which have been dealt with in previous numbers of the observer's handbook, all need a certain degree of visibility, and when flights must be made in cloud, fog, or falling snow, the navigator turns to radio navigation as the only safe and sure means of reaching his destination.

The outbreak of war, and the resulting limitation of the activities of ground direction-finding stations, has thrown extra work on to the observer and wireless operator, and new problems have been introduced by the greatly increased range of modern apparatus.

It is hoped that this book will enable the wireless operator and observer to deal with all problems as they arise, and to achieve that rapid and smooth working which is essential to good navigation.

W. J. D. ALLAN

RADIO NAVIGATION

CHAPTER I

Electricity—Alternating current—Inductance —Capacity—Oscillating circuits—Radiation —Waves—Sine curves—Reception

Most navigational textbooks dealing with Radio Navigation assume that their readers have a knowledge of the principles of wireless telegraphy, or else that such knowledge is not necessary to the navigator.

The first part of this book is written on the assumption that the latter is not the case, and that a slight knowledge of the electrical side is of value to the navigator, just as an understanding of the use of wireless bearings and fixes is of value to the wireless operator. It is felt that the time has not yet arrived when any member of an aircraft's crew can be a specialist in one subject only, and entirely removed from other fields of activity. In any case, no harm will be done in starting at the beginning, and giving a brief scrutiny to the basic electrical principles.

ELECTRICITY

All matter, whether solid, liquid or gas, is composed of atoms, and the atom is a positive nucleus surrounded by negative electrons in sufficient quantity to render it neutral. The positive nucleus is composed of protons.

If a number of electrons are removed from a number of atoms, the atoms will be positively charged, and the free electrons negatively charged. There will, therefore, be a difference of potential between the two, and if the electrons are free to do so, they will return to the atoms, thus forming a current of electricity. Currents can be made to flow in any substance that is a conductor, and contains free electrons which can be set in motion.

In order that the current should flow, it is necessary that there should be a difference of potential, or electromotive force (E.M.F.). Electromotive force may be described as electrical pressure, of which the unit is the Volt. It can be produced in a number of ways, of which the simplest is the cell.

The Cell, whether of the primary or accumulator type, can only produce about

two volts, so for higher voltages cells must be combined to form batteries. The type of current produced by cells is Direct Current (D.C.), or current which flows in one direction only. Direct current can also be produced by means of a dynamo.

ALTERNATING CURRENT

Alternating Current (Fig. 1), is current which alternates in its direction of flow. Starting from zero, it rises to maximum positive potential, then falls to zero, rises to maximum negative potential and then falls to zero again. This is known as a Cycle or Period, and the number of cycles per second is called the Frequency.

Every magnet is surrounded by lines of force which form its field (Fig. 2), and if these lines cut or are cut by a conductor, then current will be induced to flow in the conductor. The direction in which the current flows will depend on the direction in which the conductor cuts the lines of force. It should be noted that it is not sufficient for the conductor to be placed in the field of a magnet to produce a current. There must be actual relative movement between the lines of force and the conductor.

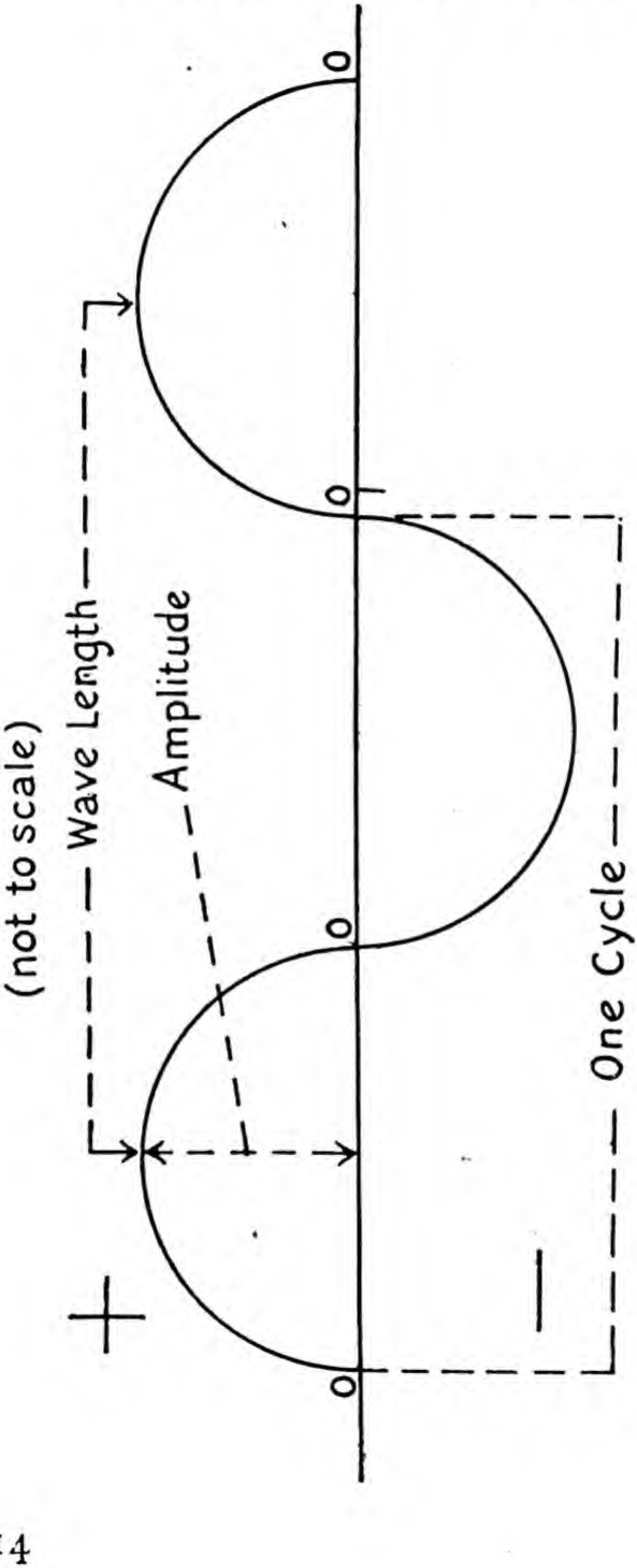


FIGURE I
GRAPH OF ALTERNATING CURRENT

Alternating current is produced by alternators and generators, of which the simplest form is a loop of wire rotating in the field of a permanent magnet.

If a loop of wire is rotated in the gap of a horseshoe magnet, the wire will cut the

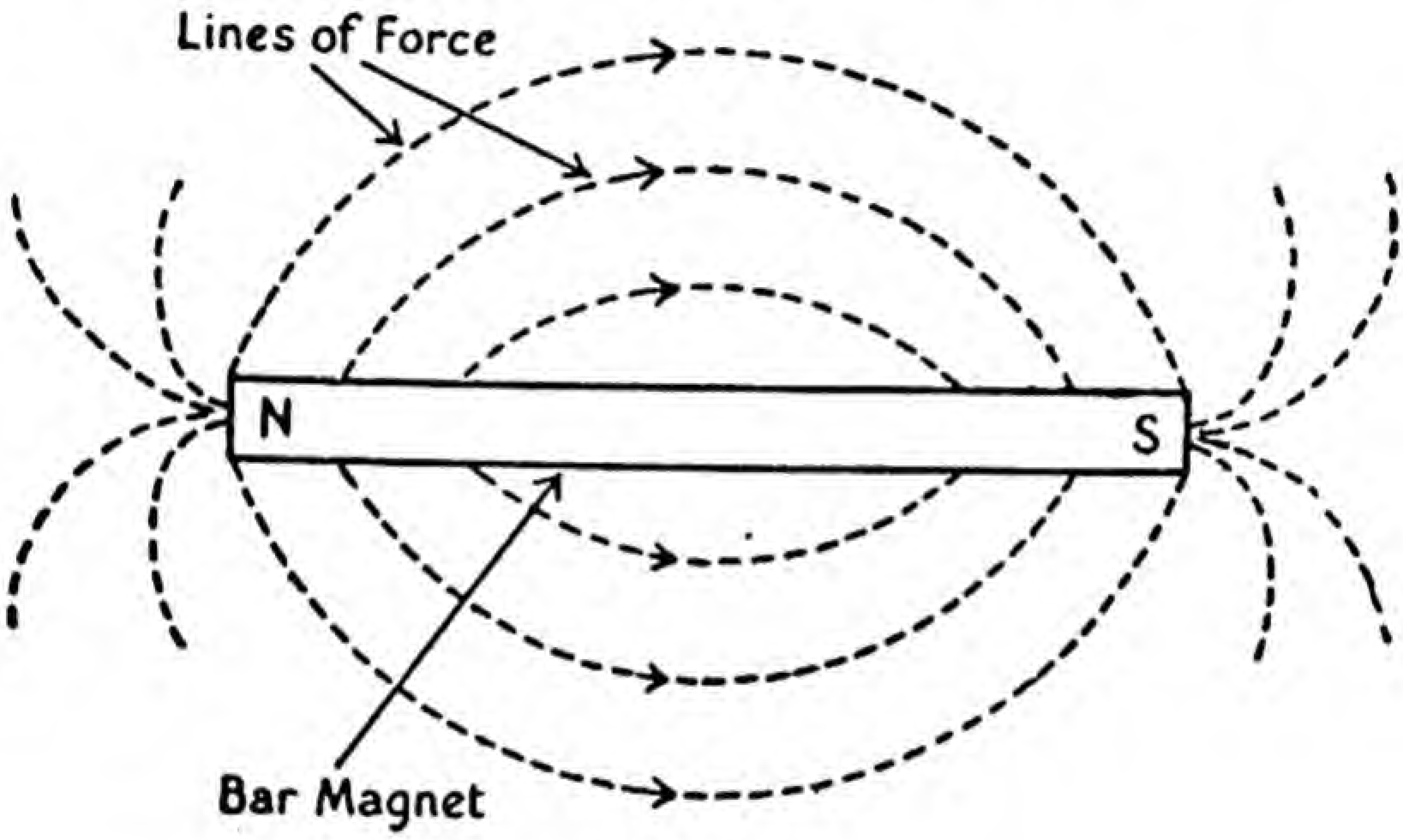


FIGURE 2
PERMANENT MAGNET

lines of force first in one direction and then in the other, as the loop is rotated, and will thus produce an alternating current. The frequency will depend on the speed of rotation of the loop.

INDUCTANCE

Any conductor carrying a current generates lines of force, like a magnet, and these

lines form concentric circles round the conductor. If these lines cut a second conductor, a current flowing in the opposite direction will be induced in it. With alternating current, the field is continually building up and dying away, and the lines of force are continually cutting and re-cutting conductors placed in the field. If a conductor is wound into a spiral coil (Fig. 3), it is known as an Inductance, and the lines of force of each turn of the coil will link the adjoining turns, and induce currents in them in a reverse direction to the flow of the current. This has a choking effect, and delays the passage of current through the coil when first switched on, and continues the flow of current for a short time after the current is switched off.

CAPACITY

Electricity may be stored for a time in a condenser, one form of which consists of two or more metal plates separated by an insulator or dielectric, such as air, mica or paper. The capacity of the condenser depends on the size and number of the plates and the nature and thickness of the dielectric.

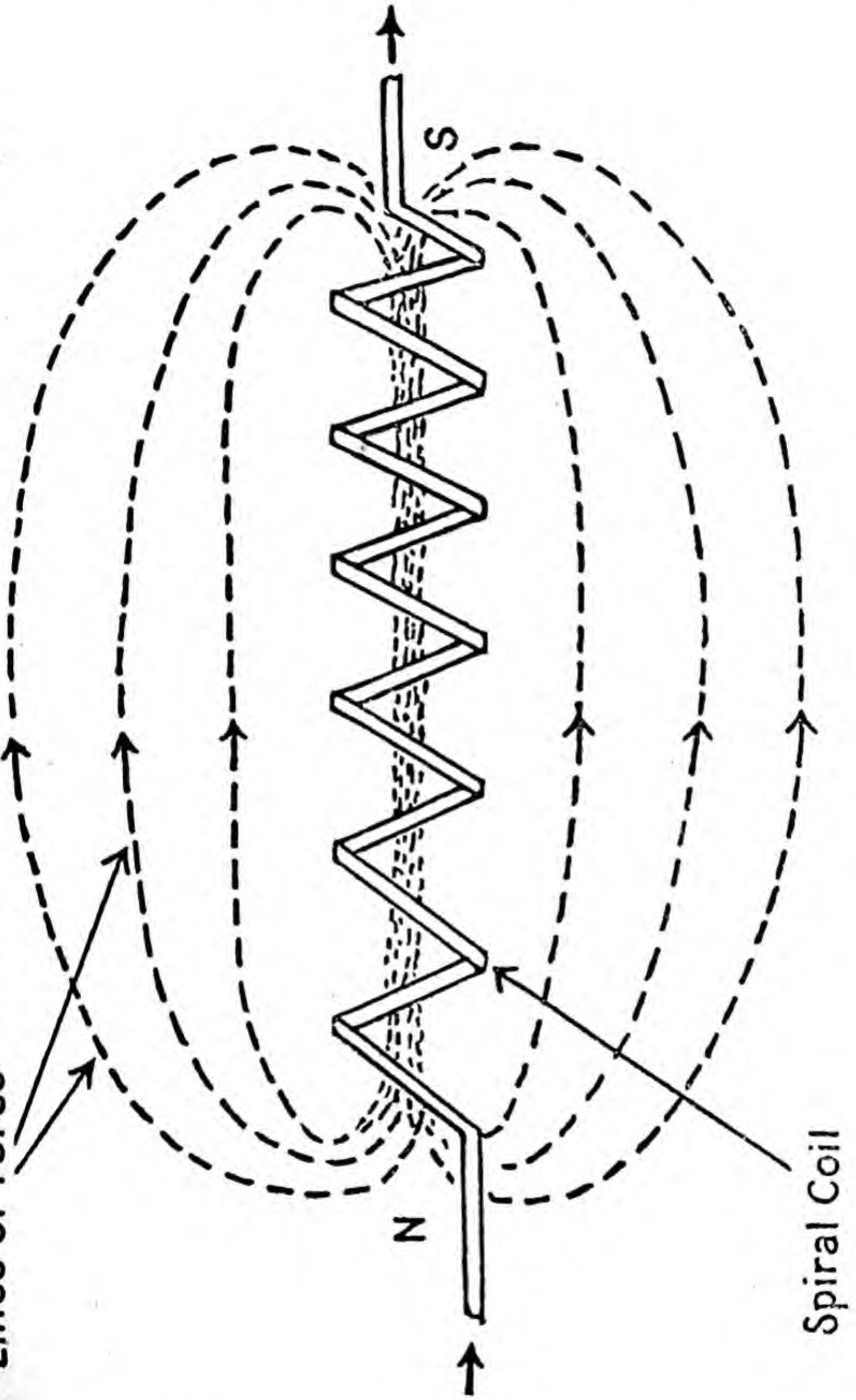


FIGURE 3
INDUCTANCE

Condensers may be either fixed or variable. If too high a voltage is put across a condenser, it will break down and a spark will jump across from plate to plate through the insulator.

The combined effect of the condensers in a circuit is known as the Capacity of the circuit, of which the unit is the Farad or Microfarad.

OSCILLATING CIRCUITS

It has been shown how an alternating current, when passed through a conductor, can induce a current in an adjacent conductor without any physical contact between the two. This in itself is a form of wireless transmission of energy, but the field of the largest inductances is very limited in extent, and other means must be found for transmission over longer distances.

For mechanical reasons, an alternator cannot produce currents of very high frequency, and as these are required for wireless telegraphy they must be produced by a special apparatus. High frequency alternating currents are called Oscillating Currents, and in order to avoid the use of very

large numbers the unit used is the kilocycle (1,000 cycles), as frequencies may be as high as 1,000 kilocycles per second. One of the simplest ways of obtaining oscillating currents was used for the early spark transmitters.

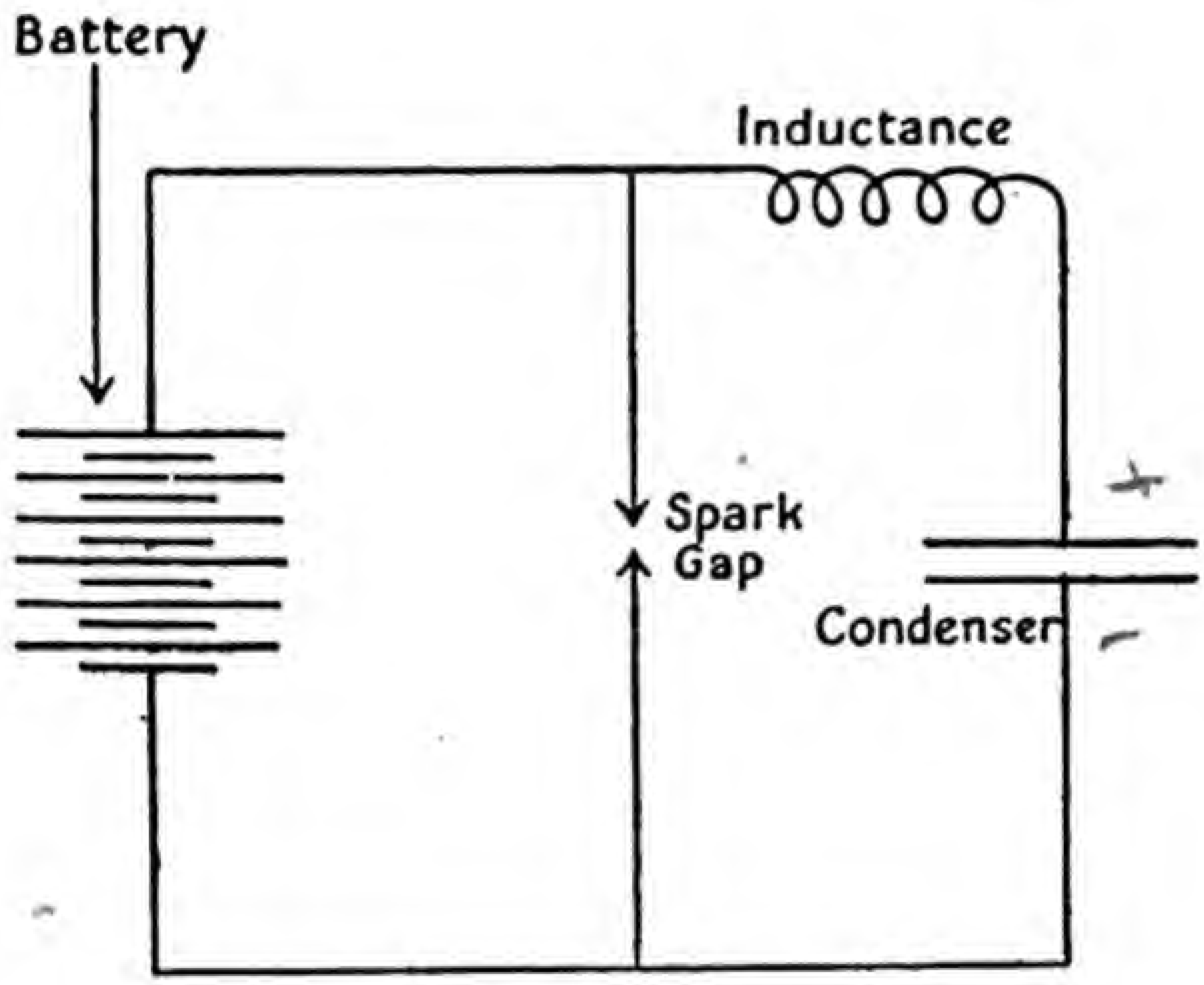


FIGURE 4
OSCILLATING CIRCUIT

Fig. 4 shows a source of D.C. supply connected to a circuit containing an inductance, a condenser and a spark gap. When the battery is first connected, the current flows into the two plates of the condenser which become positively and negatively charged. The dielectric (the air) between the plates of the condenser is now under electrical strain, owing to the difference of

5830

potential producing a tendency for the current to flow from one plate to the other. If the difference of potential is sufficiently great, or the insulating properties of the dielectric are poor, the condenser will break down.

Before the dielectric of the condenser can break down, and a current flow from plate to plate, the current finds an easier path in the spark gap, and the current passes in the form of a spark. The condenser has now discharged itself across the spark gap, but with such violence that a potential difference in the *reverse* direction is established. The spark gap will again break down and the condenser plates again reverse their polarity.

This process will continue and currents flow backwards and forwards as long as the source of supply is connected. An oscillating circuit of this type may be tuned for a desired frequency by the choice of an inductance and a condenser of suitable size. The larger the condenser, the longer it will take to charge, and the more turns of wire on the inductance, the greater the choking effect.

Oscillating circuits may be tuned with great accuracy by using suitable variable condensers and inductances.

RADIATION

We have seen that when a current flows through a conductor, a magnetic field is produced, and that an oscillating circuit causes currents to flow backwards and forwards through its conductors with great rapidity. The resulting electro-magnetic field also builds up and breaks down with similar rapidity, causing radiation, or electro-magnetic waves radiating from the conductors through the ether.

Since means are provided for tuning the apparatus, transmission can be achieved by the manipulation of the supply of electrical energy to the oscillating circuit by a switch or key.

The circuit shown in Fig. 4 may be adapted for transmission by opening it up as shown in Fig. 5. It will be seen that the two plates of the condenser are now replaced by the aerial and earth, which are the same in principle and serve the same purpose. The air between the aerial and earth serves as the dielectric between the plates of the condenser.

It will be noted that means have been provided for varying the size of the induc-

tance and tuning the circuit, and a switch introduced for controlling the supply.

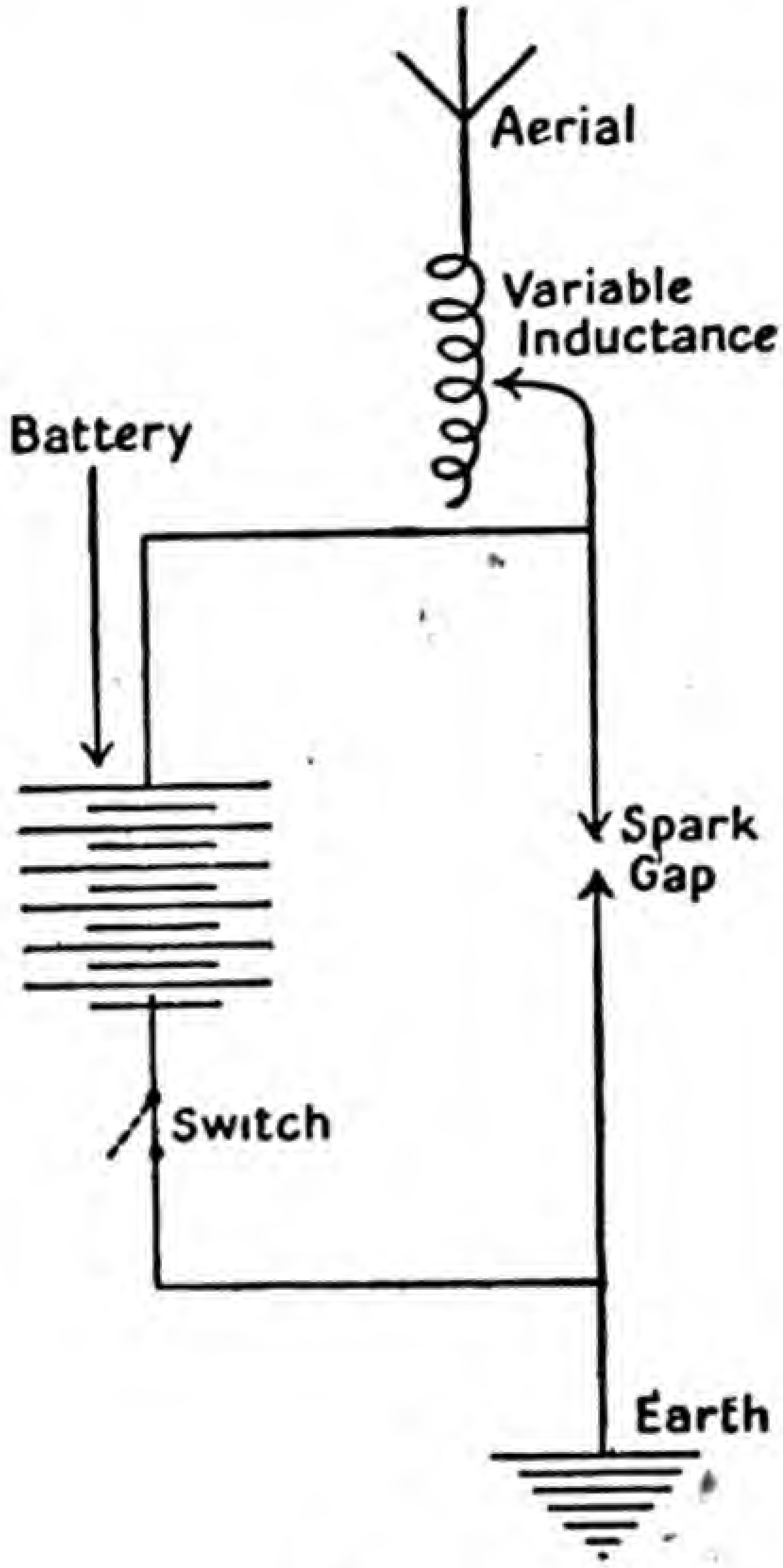


FIGURE 5
RUDIMENTARY TRANSMITTER

MODERN APPARATUS

It is not proposed to delve any further into wireless transmitters which, in their modern form, bear little resemblance to the elemen-

tary apparatus described. Moreover, modern sets are on the secret list, and no details of their construction may be published. Sufficient has been said to give some idea of a means of propagating electro-magnetic waves, and the nature of these waves will be dealt with next.

WAVES

There is a certain similarity between Hertzian waves (i.e. wireless waves) and waves in other media. To take a very simple example, suppose a rope is secured at one end and the other end is held so that the rope is nearly taut, and is then moved smartly up and down. With every up and down movement a wave will run along the rope. It should be noted that although the waves move horizontally along the rope, the actual movement of the rope is in the vertical plane. Similarly, radiations from a transmitter cause wireless or electro-magnetic waves in the ether—a medium which is supposed to permeate all matter and to have qualities similar to inertia and elasticity. Unlike the waves in the rope, wireless waves are omni-directional, travelling out through

space in all directions, both horizontal and vertical (Fig. 6). The actual wave front should be visualized as an almost vertical plane reaching to a great height and concentric to the transmitter.

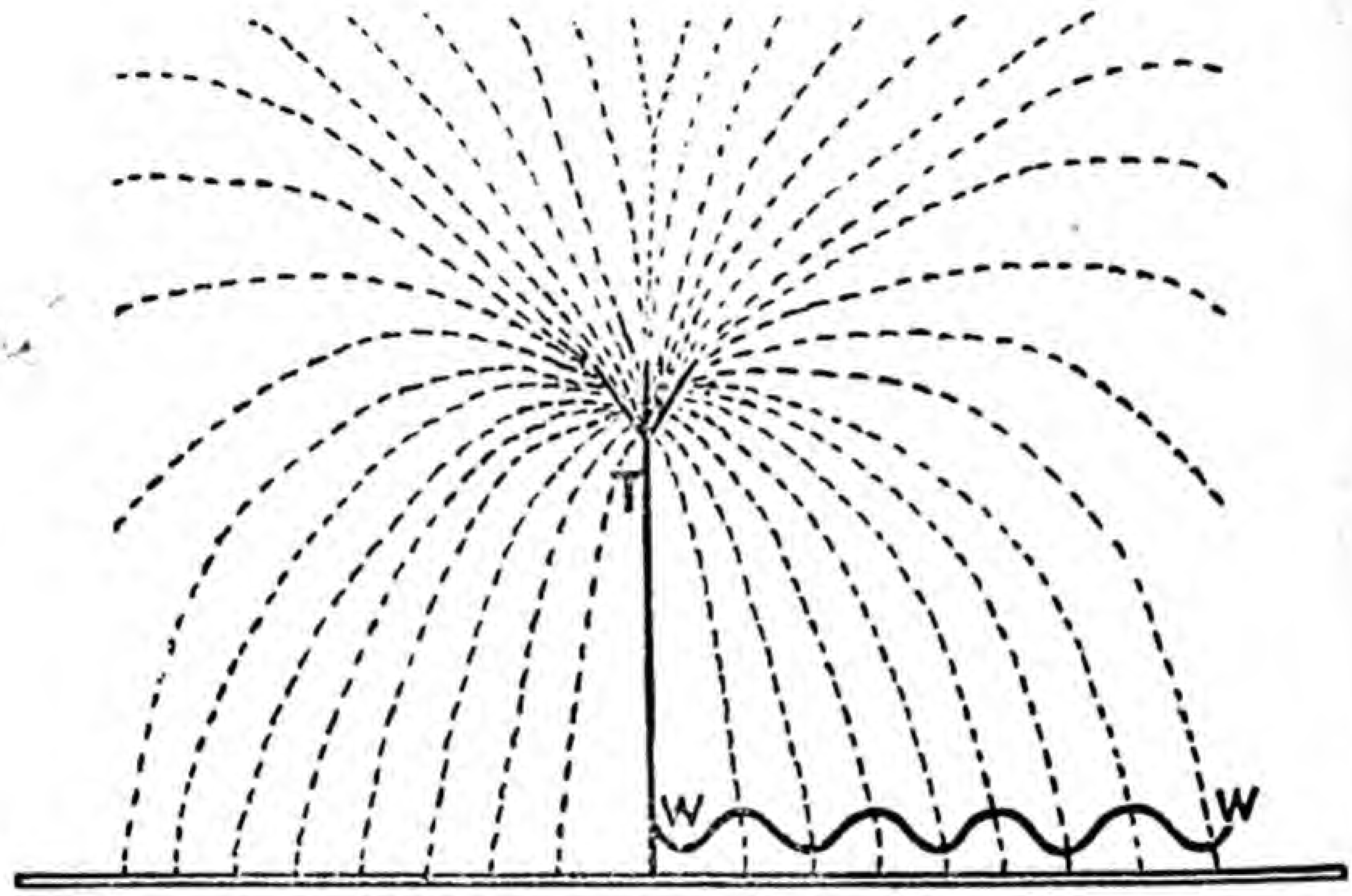


FIGURE 6

T = Transmitting Aerial. W–W = Graph of Wave.

A graph may be made showing the points round a transmitter at which signals are received at equal strength. If a simple vertical aerial is used for transmission, the graph —which is called a polar diagram—will be as in Fig. 7. At all points on the circle surrounding the transmitter reception will be at equal strength.

Wireless waves pass through nearly all substances which are *not* conductors of electricity, but may be diverted, reflected or

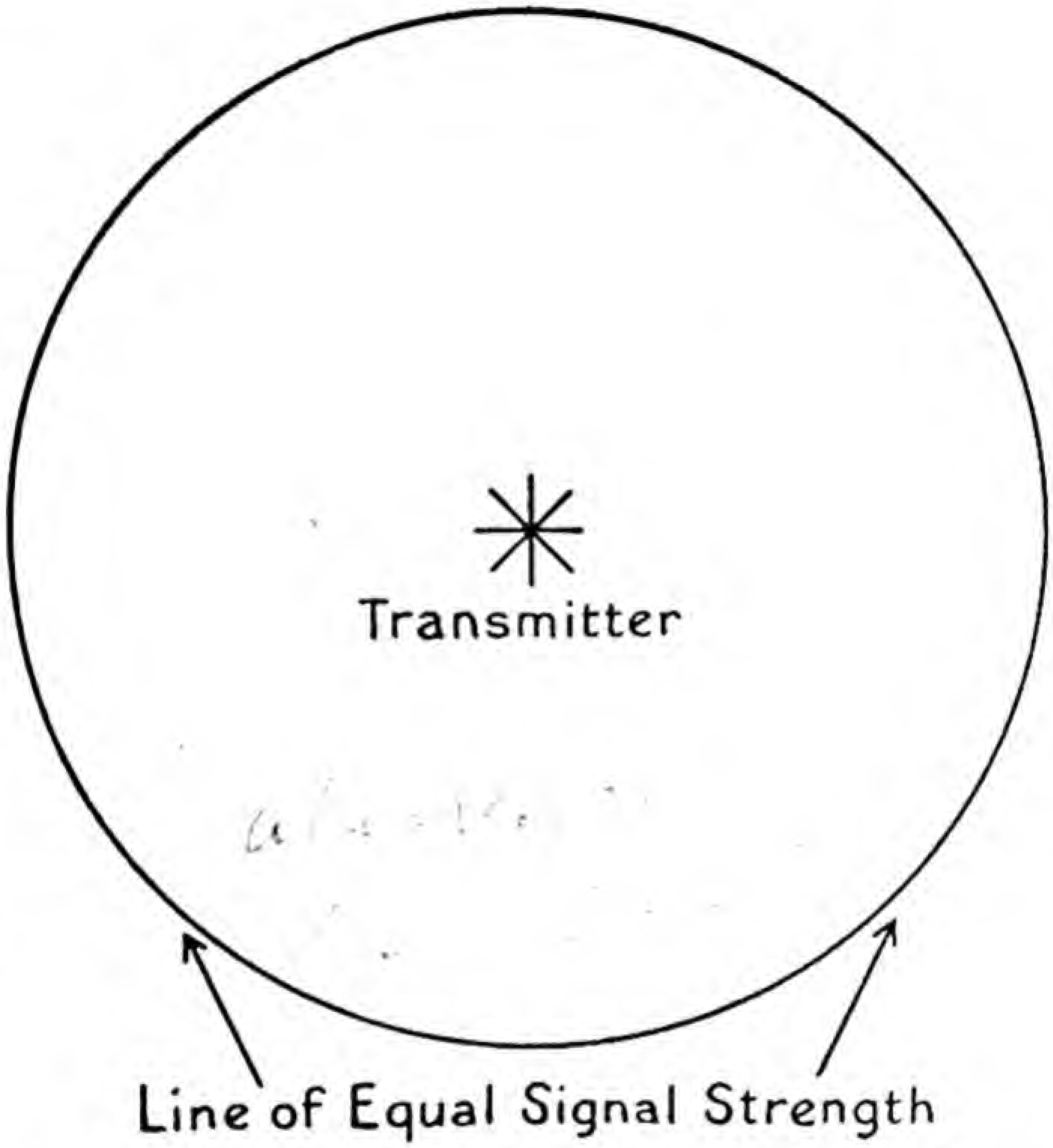


FIGURE 7
POLAR DIAGRAM FOR VERTICAL AERIAL

absorbed by substances which *are* conductors.

Wireless waves travel at the same speed as light waves, which travel at 186,000 miles per second, or approximately 300 million metres per second. The wave length is the

distance between adjacent wave crests and can be found by dividing the speed of the wave by its frequency. Thus, with a frequency of, say, ten million cycles per second, and a speed of three hundred million metres per second, the wave length is thirty metres. The actual distance the waves travel is dependent on their amplitude or strength when propagated. The farther they go, the more attenuated they become. The strength of the magnetic field at any point is given as the "flux density." It is the number of imaginary lines of force per unit area, and is sometimes shown graphically as a series of parallel lines. The closer the lines, the stronger the field.

SINE CURVES

If the instantaneous values of a wireless wave are plotted as a graph, it will be found that the graph takes the form of a sine curve or sine wave. The nature of a sine wave is shown by Fig. 8 and Fig. 9. In Fig. 8 the distance AB—the radius of the circle—is taken as unity or 1, and all other lengths in the figure are relative to it.

Now let the top right-hand quadrant of

the circle be divided into four sectors by the lines AC, AD and AE. From the line AB erect perpendiculars *c*C, *d*D, *e*E. These, then, are the sines of their respective angles, *c*C

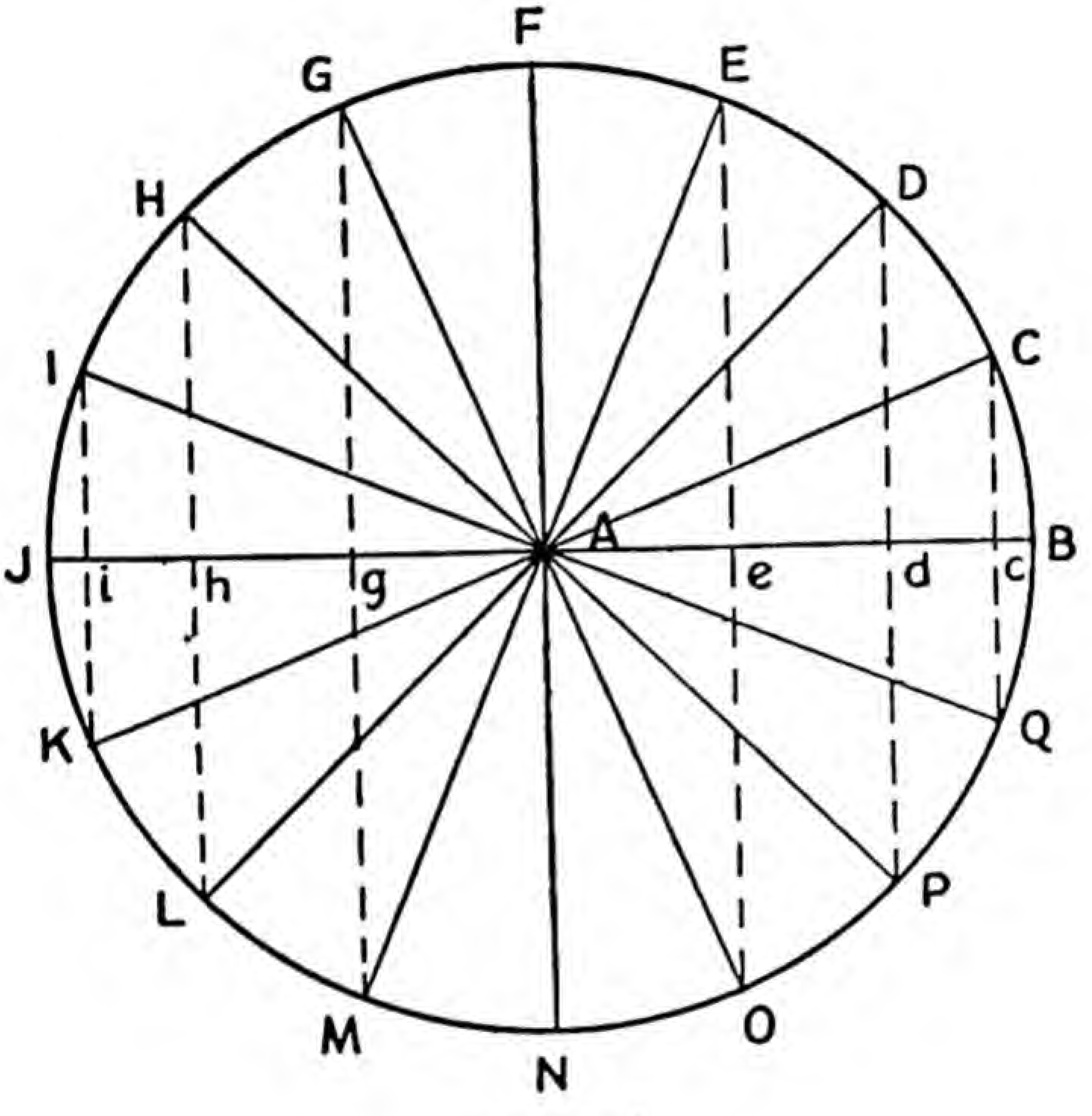


FIGURE 8

being the sine of angle CAB ($22\frac{1}{2}°$). The sine is really the ratio between two sides of a right-angled triangle. In this case, the sides are *c*C (the perpendicular) and AC (the hypotenuse). It will be seen that AC equals AB, which equals unity or 1, so that the sine

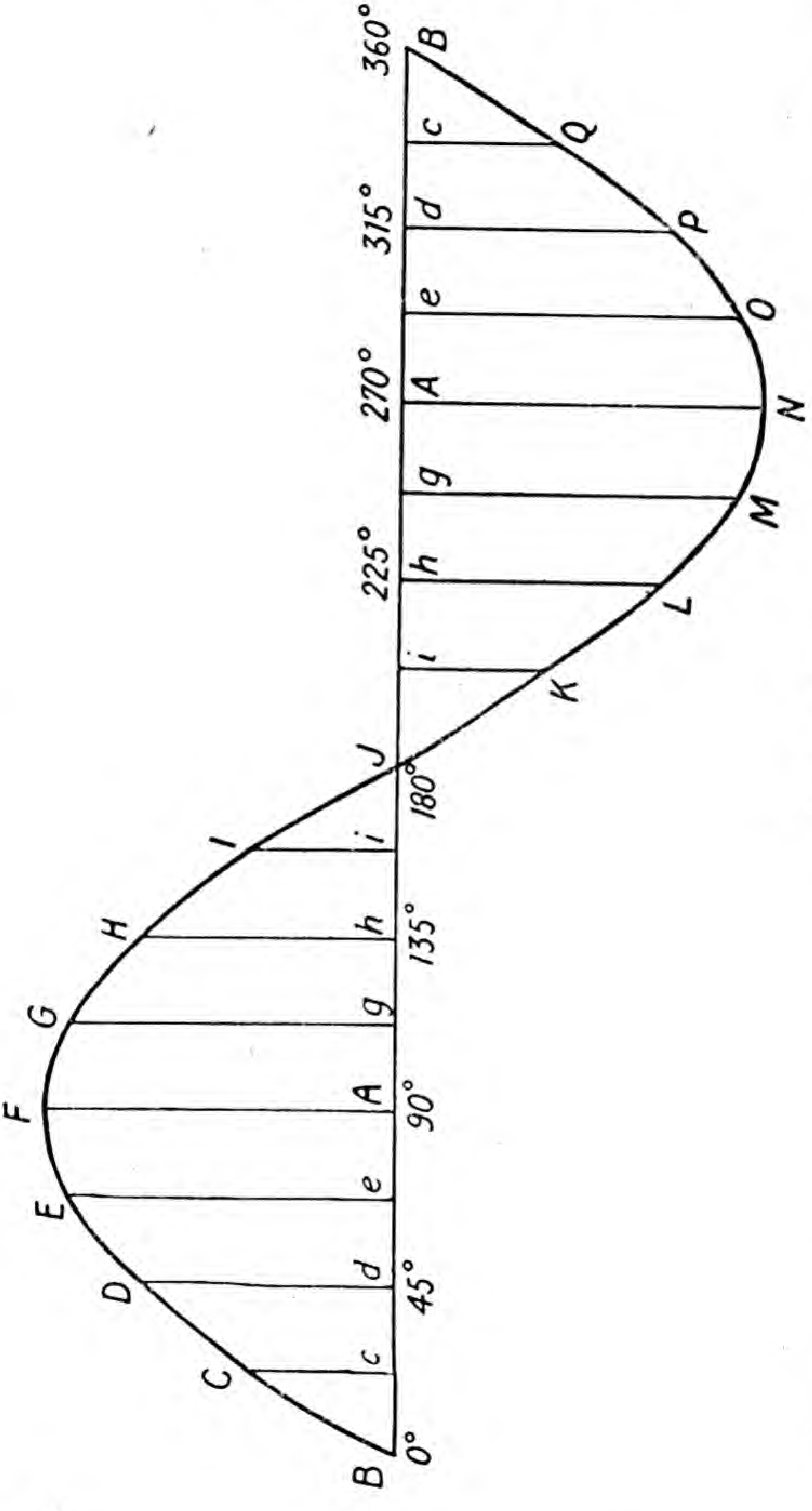


FIGURE 9
SINE CURVE

of angle CAB $= \frac{cC}{1}$. It may be expressed as a decimal fraction, i.e. 0·382683.

If the line AB is rotated right round the circle, the sine ratio value will commence at zero at AB and rise to 1 at FA, fall again to zero at JA and rise to 1 on the negative side at AN. The cycle is completed at zero at AB.

Thus all intermediate values may be plotted along a line and a curve drawn through the different points as shown in Fig. 9.

If the instantaneous values of a wireless wave are plotted for a length equivalent to the wave length (reduced to scale) they will take a form similar to that in the figure.

RECEPTION

Just as a current is produced in a conductor when it is cut by the lines of force of a magnet, so electro-magnetic waves cause currents to flow in conductors placed in their path. These conductors are known as aerials or antennae, and usually take the form of electrically balanced "T's" or "L's." The earth wire of the set is connected to the

fuselage of the aircraft. All metal parts of the aircraft are electrically bonded—that is joined together by wire—in order that the "earth" may have as large a capacity as possible.

For long range work, the "T" or "L" aerial may be replaced by a trailing aerial which is reeled out when actually in the air.

The currents received in the aerial are transformed by the receiver from the radio frequency of the wireless wave to the much lower audio frequency which will operate headphones, and enable speech or morse signals to be heard.

Telephony—in which speech is heard—is quite simple to operate, but rather less reliable than telegraphy, and has a shorter range. The usual procedure is to instal telephony if an aircraft does not carry a wireless operator, and telegraphy if it does. Some large machines have both.

Most aeronautical wireless stations work on wave lengths between eight hundred and nine hundred metres, and owing to the closeness of many of the wave lengths, great care must be taken in tuning. Radio transmitting and receiving sets have many uses, the more important including communication with

the control officer or the base; exchanging warnings of dangers to navigation with other aircraft; and the reception of meteorological information. The latter is usually given in three-letter code groups, and is known as the Q Code, as each group begins with the letter Q.

When approaching to land at an aerodrome in conditions of poor visibility (QBI) this code is used to ask for and obtain the barometric pressure at aerodrome level, in order that it may be set on the subsidiary scale of the sensitive altimeter, and thus enable the exact height above the aerodrome to be obtained. Before leaving an aerodrome on a cross-country flight, wireless communication should be established with the ground station, in order to ensure that the apparatus is working satisfactorily, and when landing at the destination the local ground station should be informed that the aircraft station is closing down.

A wireless log of all messages sent and received is kept, and no message may be sent without the authority of the captain of the aircraft.

CHAPTER II

The directional loop—Types of D/F loops —"Sense"—The "Sense" aerial—Bearing and "Sense" scales—The cardioid—The visual indicator

THE DIRECTIONAL LOOP

Fig. 10 shows a number of aerials and a sine curve representing the E.M.Fs. set up in them by a wireless wave. It must be emphasized that the diagram does not attempt to show a wireless wave pictorially. Aerial "A," which is a plain vertical aerial, is in a part of the wave in which the E.M.F. as indicated by the curve is maximum negative. Aerial "B" is at a point at which the wave is at zero potential, and aerial "C" is placed at maximum positive. Now, if two vertical aerials are taken (D and E) and joined at top and bottom to form a loop, it will be seen that aerial "D" is at a part of the wave which is at higher potential than aerial "E." A current will therefore flow from D to E, owing to the difference of

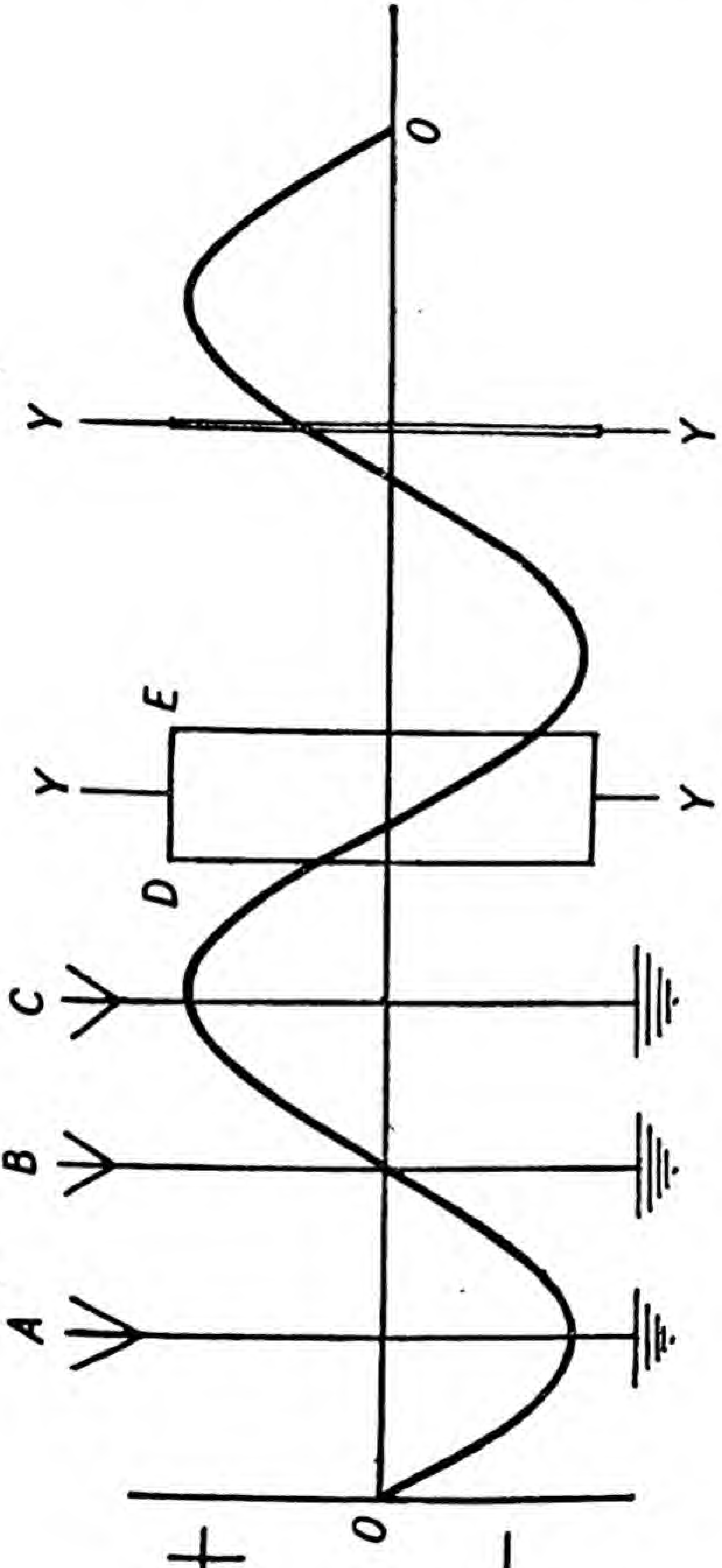


FIGURE 10
THE DIRECTIONAL LOOP

potential. If the loop is now rotated through 90° about "YY," as at the right-hand side of Fig. 10, both sides of the loop will be at the same potential and no current will flow. The whole practice of direction finding wireless is based on this principle.

It will be realized that if the loop is again turned through 90°, in the same direction, it will again be parallel to the path of the wave and current will flow. Thus, in a complete revolution of the loop there will be two positions of maximum signals and two of zero signals.

The effects can best be seen by reference to Fig. 11, which is a polar diagram of a loop aerial. The loop is shown in the centre (LL) receiving signals from a series of equi-distant transmitters (1, 2, 3, etc.) situated on the outer circle. The strength of the signals received is shown by the distance from the centre of the loop to the different points on the two smaller circles. Thus, signals received from Transmitter 1 will be at a maximum and are represented by the full diameter of the circle. No signals will be received from Transmitter 5 as the loop is at right angles to the path of the in-coming signals. The signal strengths for Transmitters 2, 3

and 4 are shown by the dotted lines B C and D. The diagram is called a Cosine Polar Diagram, because the signal strength varies

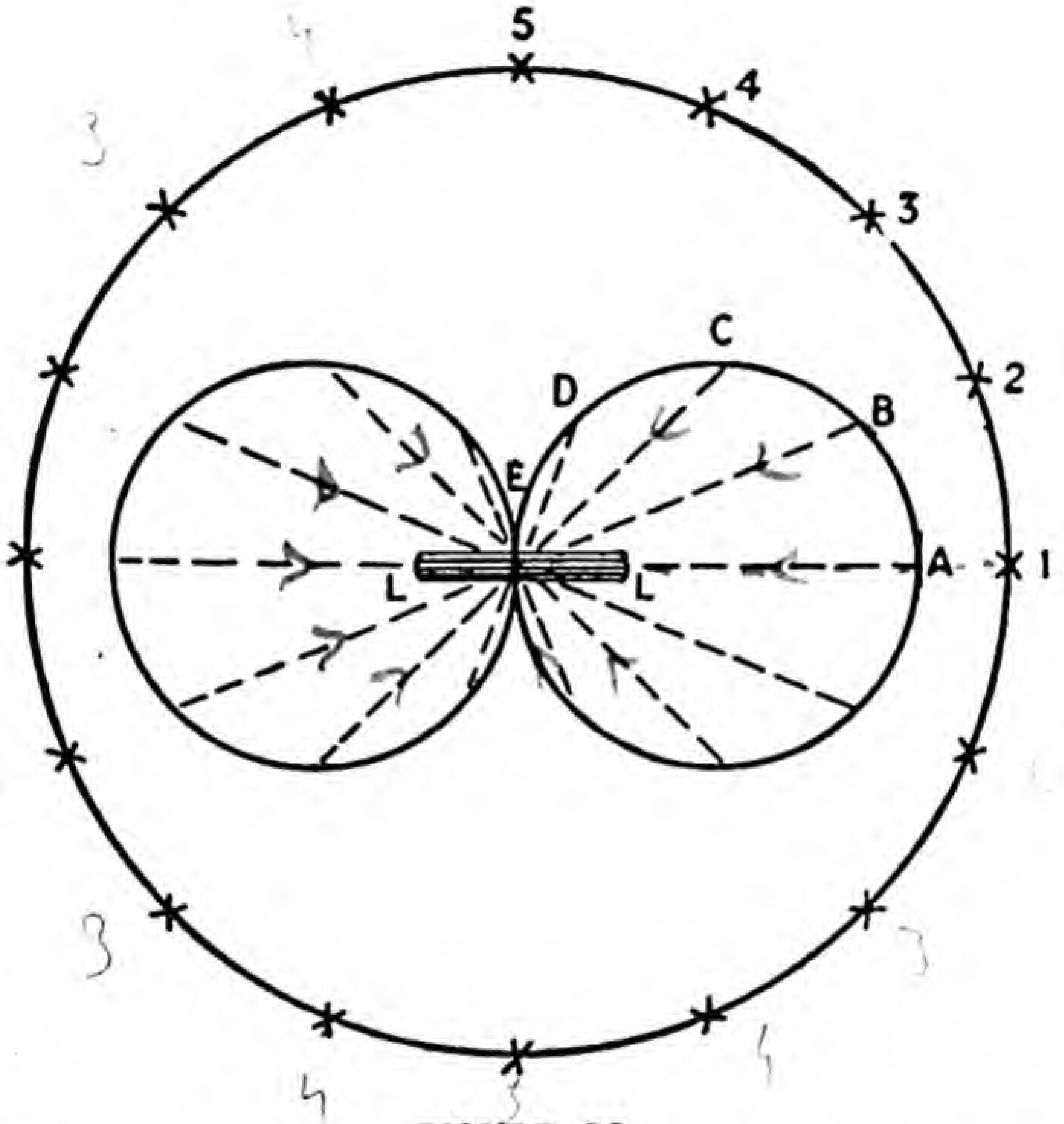


FIGURE 11
COSINE POLAR DIAGRAM FOR LOOP AERIAL

as the cosine of the angle between the incoming wave and the plane of the loop.

Turning back to Fig. 8, it will be seen that the sine of angle CAB was *c*C. The cosine of this angle is *c*A. A cosine curve can be constructed in a similar manner to a sine curve, and will appear as in Fig. 9, except

that there will be a 90° difference of phase or, in other words, the cosine curve will be at a maximum when the sine curve is at zero.

Returning to Fig. 11, it will be observed that the difference between the strength of the signals received from Transmitters 1 and 2 is quite small, whereas the corresponding difference between numbers 3 and 4 is very large, in spite of the fact that the distance between 1 and 2 is the same as between 3 and 4.

In Fig. 11, the loop is stationary in the middle of a circle of transmitters, but the cosine polar diagram will be identical if the loop is rotated relative to a single transmitter. In short, it will be found that the signal strength varies as the cosine of the angle between the incoming wave and the plane of the loop, and that the change of strength for a given rotation of the loop is most marked near the minimum position and least noticeable near the maximum.

It follows, therefore, that to take an accurate bearing of a transmitter the loop should be turned until the signal heard dies away to a minimum, in which position the loop may be assumed to be at right angles

to a line joining the aircraft and the transmitter.

The usual procedure in finding the minimum is to turn the loop until the signals fade out, note the scale reading, and then turn the loop in the same direction as before until the signals are heard again. The minimum position will be mid-way between the two positions.

The line joining the aircraft to the transmitter is known as a position line, and before it can be plotted on a map the angle it makes with the true meridian must be ascertained. The loop aerial carries a scale graduated from 0 to 360°, which is rotated against a pointer or index mark set in the longitudinal axis of the aircraft. When the loop is at right angles to the longitudinal axis, it is in a position to receive minimum signals from a transmitter directly ahead of the aircraft, and the loop scale will read zero. The scale reading gives the angle between the longitudinal axis of the aircraft and the incoming wave, and before it can be plotted as a position line, the true course of the aircraft must be added to it. The plotting of position lines will be described later.

TYPES OF DIRECTION FINDING LOOPS

There are several types of loop in general use, one of the most common consisting of a rotatable metal sheath about 20 inches in diameter, which contains a dozen or more turns of insulated wire, the two ends of which are connected to the receiver through slip-rings. The number of turns in the loop aerial is governed by the wave length to be used and the diameter of the loop. The smaller the diameter, the greater the number of turns.

The metal sheath protects the coil from the elements, keeps it in shape, and serves as a shield against static effects. The sheath (Fig. 12) is broken at one point by the insertion of an insulating segment, which prevents the metal sheath from isolating the loop aerial from the radio waves.

D/F loops of this kind may be mounted above or below the fuselage, but they offer a certain wind resistance and reduce the speed of the aircraft. Another type of loop is rotated inside a stream-lined housing which is secured above the fuselage, while a third type is oval in shape and is retractable. This is probably the most practical form.

Loops of small diameter may be con-

structed by winding insulated wire round a container filled with iron dust, which increases the efficiency of the loop. Such a loop will offer less resistance to the air owing

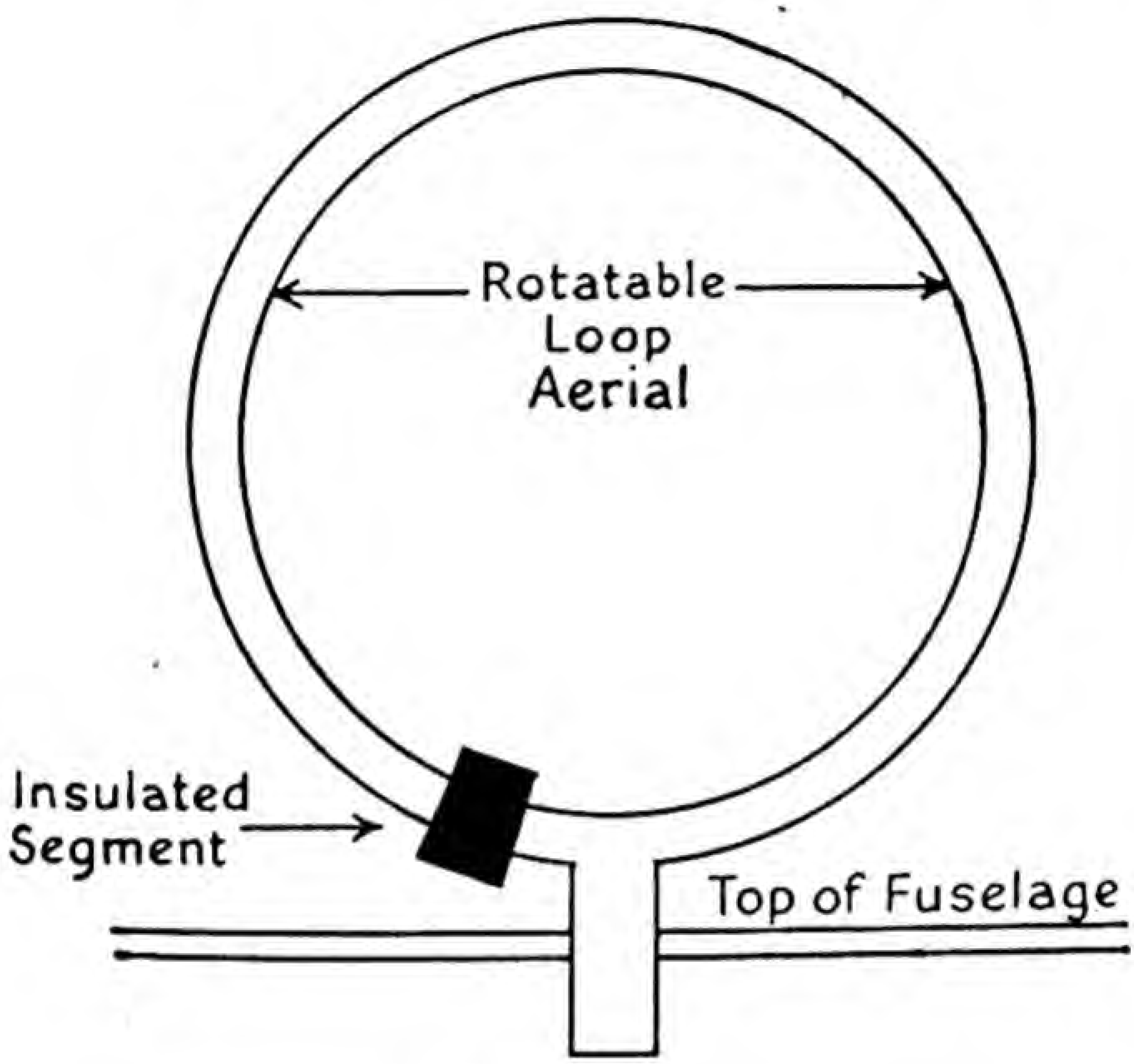


FIGURE 12
ROTATABLE LOOP AERIAL

to its size, but the disadvantage is its additional weight.

"SENSE"

It has already been explained that in a complete revolution of a D/F loop two positions of minimum signals will be found,

and that these are 180° apart. In other words, what is obtained from a loop bearing of a transmitter is a position line passing through the transmitter and the aircraft. The latter may be on any part of the position line, and on either side of the transmitter, and the navigator must use one of four methods to find the sense of the bearing, that is, whether it is the bearing or its reciprocal that he has taken.

The first method is by means of an approximate dead reckoning position. If the navigator knows that his D/R position is not more than a few miles in error, and he takes a bearing of a W/T station which is some distance away, he should have no difficulty in deciding which is the bearing and which the reciprocal.

The second method is by change of bearing. In Fig. 13, an aircraft is flying on a track of 278°T, and at 04·00 hours takes a loop bearing of a transmitter A. There are two minimum positions of the loop, and the bearing is either 000° or 180°, and when laid off through A gives BAC. The aircraft is somewhere on this position line, but may be on either side of the W/T station. A few minutes later a second bearing of the same

station is taken, and found to be 030° or 210°. This position line is also laid off through Transmitter A, giving DAE. Examination

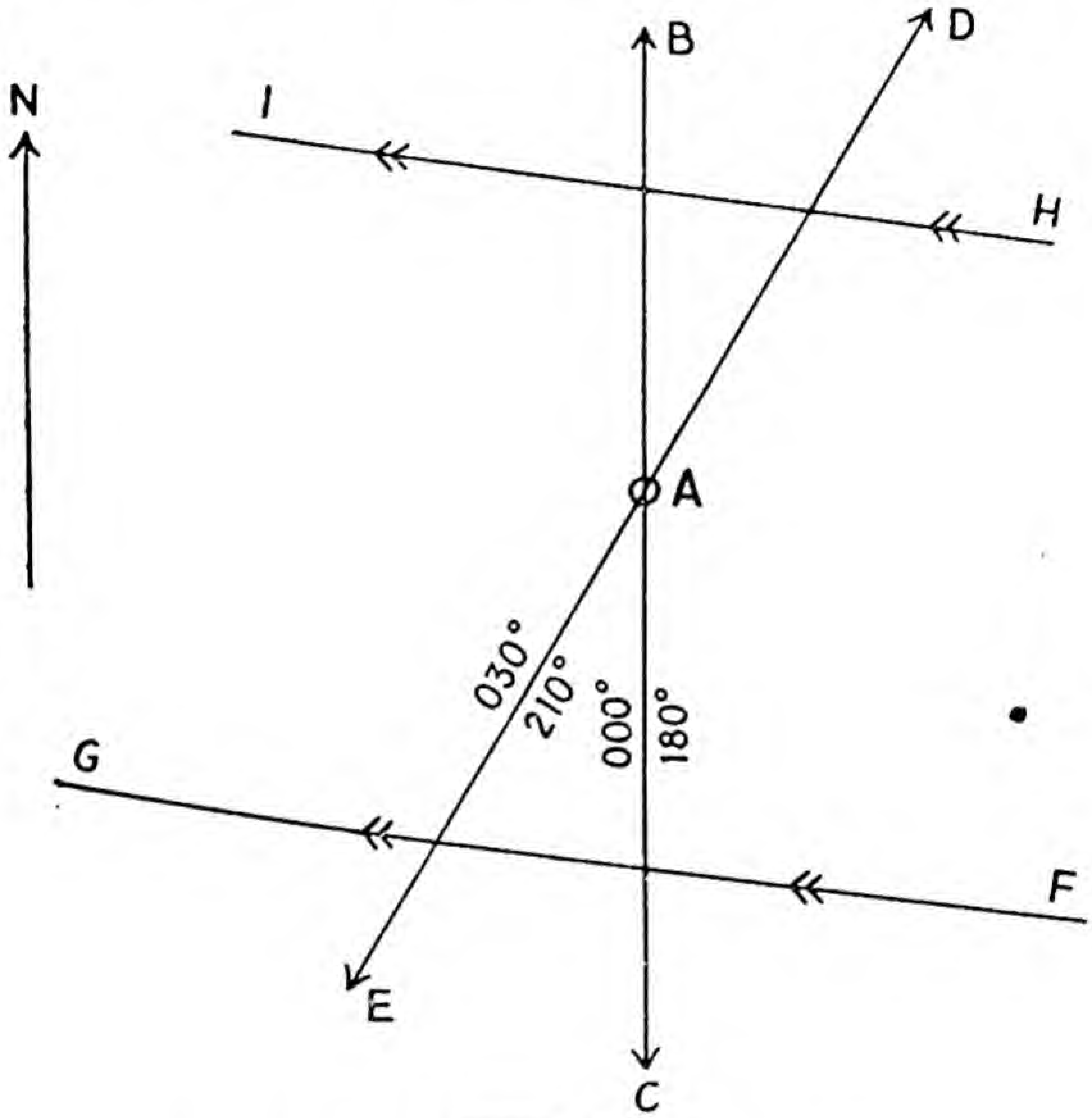


FIGURE 13
SENSE BY CHANGE OF BEARING

of the two position lines makes it obvious that the aircraft must be on the south side of the transmitter, flying along a line parallel to FG, and that the bearings must have been

000° and 030°. Had the aircraft been on the north side, flying parallel to HI, the bearings would have been received in the opposite order, i.e. 210° first and then 180°.

The experienced navigator will be able to visualize this procedure and plotting will be unnecessary to determine sense.

THE "SENSE" AERIAL

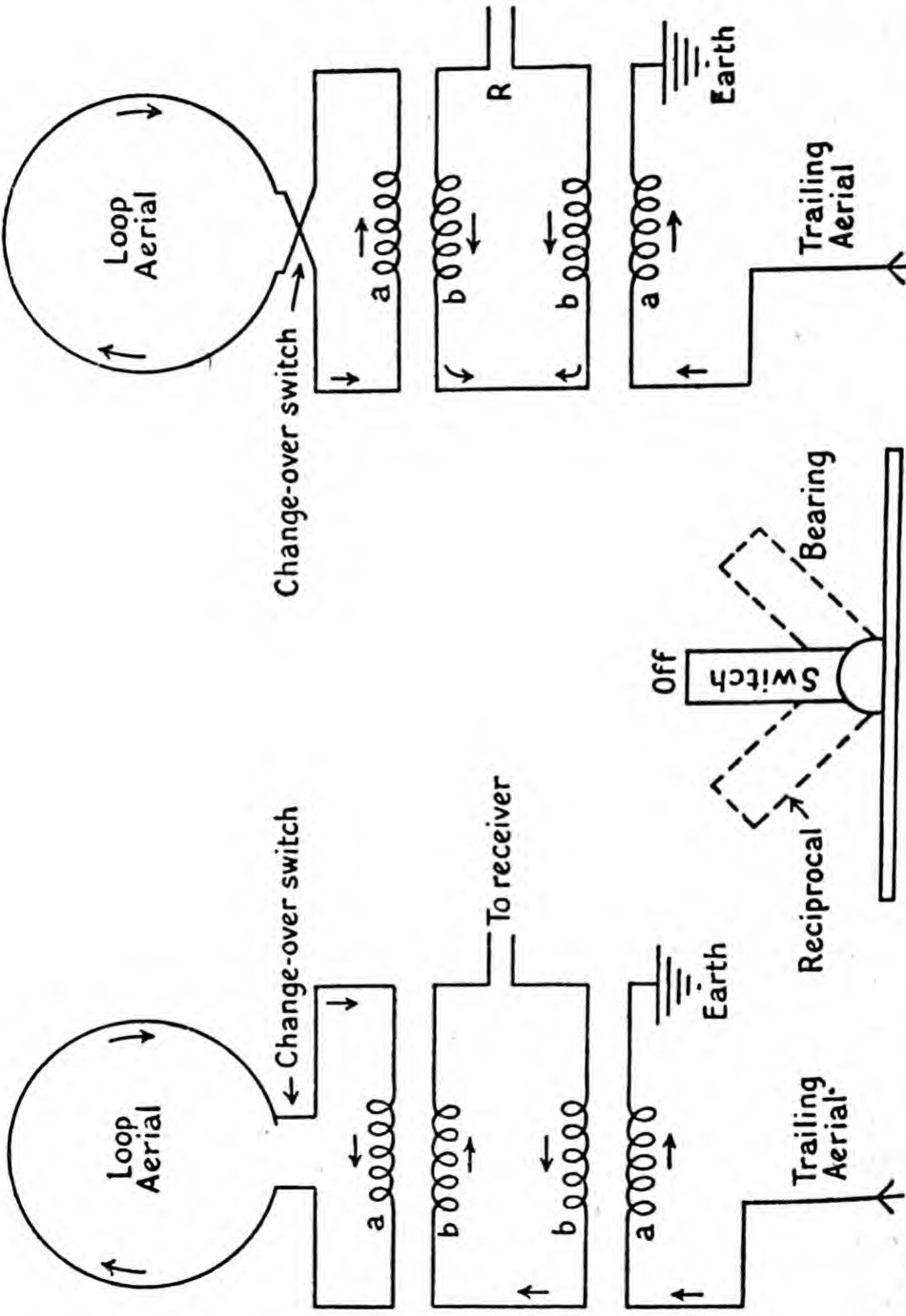
The third method of finding sense is by means of a sense aerial, a trailing aerial usually being employed for this purpose. When taking a bearing, after the minimum position has been found and noted, the loop is turned to the maximum position, that is, through 90°, and the loop and sense aerials are matched, or tuned to the same wave length; the sense aerial is adjusted to give the same signal strength as the loop maximum. The current from the two aerials is connected to the receiver by means of a change-over switch which has three positions. When in the centre position, the loop only is connected to the receiver. With the switch to the left or right, the output of the two aerals is mixed, the difference between the two positions of the switch being that in one

position the connections of the loop are crossed over, so that the direction of flow of the current from the loop is reversed, relative to that from the sense aerial. This is equivalent to turning the loop itself through 180°.

Fig. 14 shows diagrammatically the operation of the change-over switch. The left-hand side of the figure shows the relationship between the loop aerial and the trailing (sense) aerial, when the switch is in the position marked "reciprocal." At a given instant in time, the radio wave is inducing current in the two aerials as indicated by the arrows. The aerials are inductively coupled to the receiver so that the current flowing in "*a*" produces an equal but opposite current in "*b*." It will be noted that the currents produced in the receiver circuit by both aerials flow in the same direction, so that the signal strength of the combined aerials will be double that of either one.

The volume obtained in this condition is the absolute maximum obtainable with the two aerials so coupled.

The right-hand side of the figure shows the switch in the "bearing" position. Current is flowing in both aerials in the same direc-


Loop Aerial
Change-over switch
a
b
R
Earth
Trailing Aerial
Bearing
Off
Switch
Reciprocal
Loop Aerial
Change-over switch
To receiver
a
b
Earth
Trailing Aerial

tion as before, but the ends of the loop have been crossed over so that the flow of current in the inductance coil is in the opposite direction. It will be seen that the currents induced by the two aerials in the receiver tend to flow in opposite directions, so that they cancel out and no signals are heard. This, then, is the minimum position with matched aerials.

Having got rid of one minimum and the sense ambiguity, it remains to describe the method of reading sense.

BEARING AND "SENSE" SCALES

The rotatable loop carries a graduated scale (Fig. 15A) which reads zero when the loop is in a position to get minimum signals from a transmitter directly ahead of the aircraft, i.e. when the loop is athwartships. Below this scale, which is usually white, is a red scale graduated in a similar manner from 0° to 360°, but with the graduations 90° displaced from the white scale, so that 90° on the white scale is opposite zero on the red.

Let us suppose that the operator is taking a bearing and has turned the loop to the minimum position. The white scale reading

is, say, 80° and the operator wishes to know whether this is the bearing of the station or

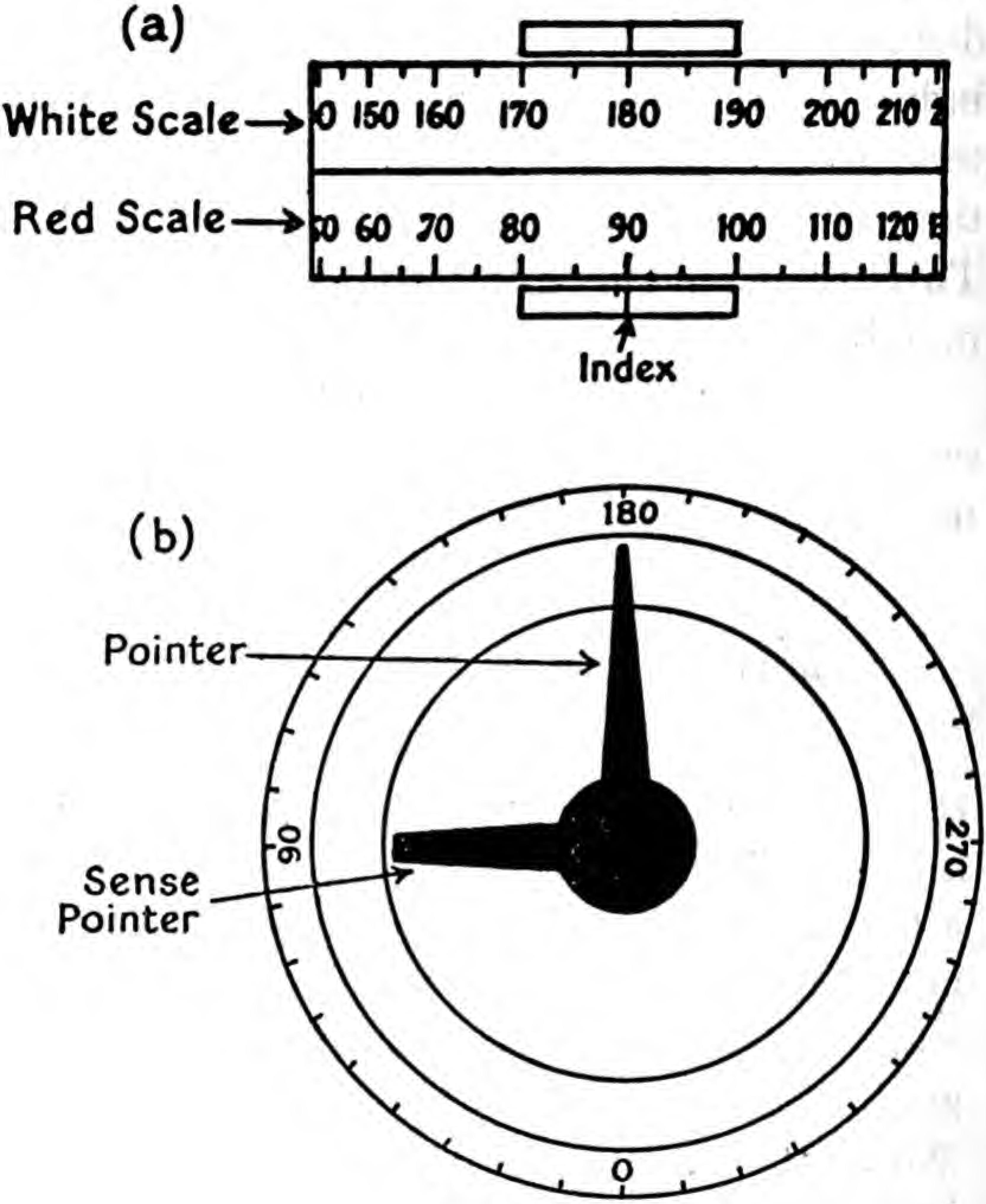


FIGURE 15
SCALES

its reciprocal. He turns the loop until it reads 80° on the *red* scale, that is he turns it clock-

wise through 90° to the maximum position. The change-over switch is now operated backwards and forwards, and the position of the switch when minimum signals are heard will tell him whether 80° is the bearing or its reciprocal. If minimum signals are heard when the switch is on reciprocal, then 180° must be added to the scale reading and the bearing is 260°. The course is now added to get the true bearing for plotting.

When the D/F apparatus is first installed in an aircraft, the relative positions and connections of the loop, the loop scale and the change-over switch are tested with the help of a transmitter whose position and bearing are known. Once fixed, the relationship is permanent.

It may be asked why the sense minimum is not used for the actual bearing, but unfortunately it is usually too coarse and wide to give direction accurately, the loop minimum being much crisper and more accurate.

With some aircraft, the loop aerial is in an inaccessible position, and is therefore fitted with remote control. It is turned by means of a flexible cable, and its angular position is indicated by a pointer on a dial. This pointer is long and sharp, and carries a

second or "sense" pointer which is short and blunt, and is displaced by 90° relative to the bearing pointer (Fig. 15B).

The method of manipulating the loop and switch is similar to that described above.

THE CARDIOID

The polar diagram for the combined loop aerial and sense aerial is heart-shaped, and is called a cardioid.

Fig. 16 shows the simple figure-of-eight cosine polar diagram of the loop aerial, and also the circular diagram of the sense aerial surrounding the figure-of-eight. The loop is rotatable about the point A. At the instant of time for which the diagram is made, the sense aerial is at positive potential and the loop aerial may be positive or negative according to the angle it makes with the incoming wave. The maximum positive for the loop is represented by AB, which is identical with the potential of the sense aerial. The maximum negative for the loop is represented by AC.

The cardioid is plotted by finding the algebraic sum of the potentials in the two aerials at different points.

At AB, for example, both aerials are positive, and both are at their maximum value, so AB + AB = AW.

At AC, both aerials are of the same value,

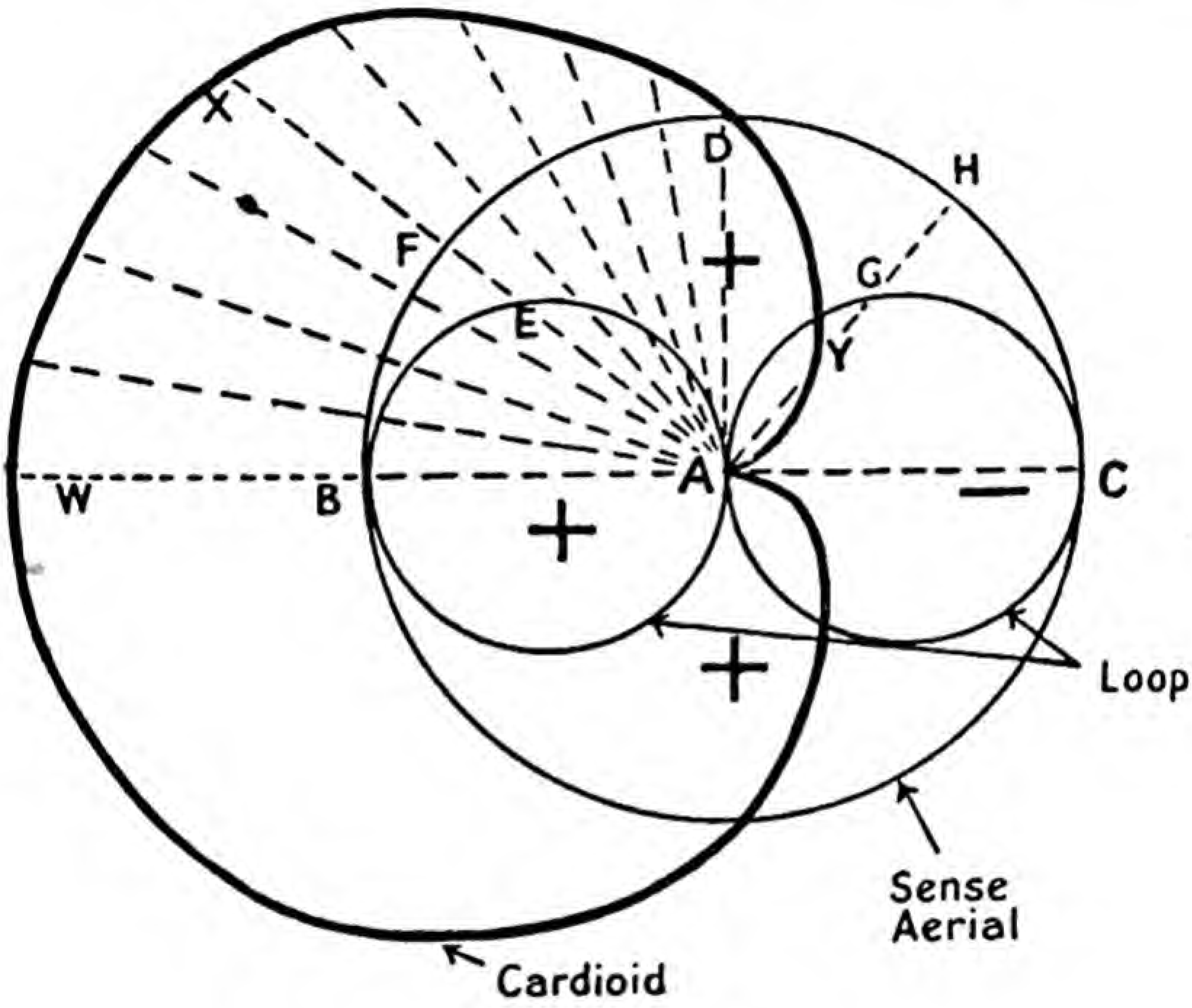


FIGURE 16
THE CARDIOID

but the loop is negative and the sense aerial positive, so the resultant is AC − AC = Zero. For the direction AD the loop is at zero so the value plotted must be that of the sense aerial only, i.e. AD.

Where the loop value is AE, the sense value

is AF, so AE + AF = AX. Similarly, with the sense value AH and the loop value – AG, the cardioid value is AY.

The cardioid shows that the combined aerials have only one minimum, and that that minimum is displaced 90° from the loop minimum.

THE VISUAL INDICATOR

The fourth way of finding sense is by means of a visual indicator. This instrument is really a small centre-zero meter, and the pointer gives indications by moving to the left or to the right. When the loop aerial is at right angles to the incoming wave, and no current is flowing, the pointer of the visual indicator remains central, but if the loop is turned to left or right the pointer will move to one side or the other, depending on which side of the loop the signals are coming from.

If the loop is turned clockwise, and the pointer moves to the right, then the scale reading is correct, but if it moves to the left, then the scale reading is the reciprocal of the bearing and 180° must be added to it.

Unfortunately, the operation of visual

indicators has not been standardized by the various manufacturers, and some indicators read the opposite way, but in any case it is a small matter to find the way to read any particular indicator, once the principle is known.

There are also certain indicators that have two pointers instead of one, and with this type the indication is given by the movement of one or other of the pointers towards the centre.

CHAPTER III

D/F loop errors—Coastal refraction—Heavy static—Antenna effect and "Pick-up"—Quadrantal error—Method of calibration—Night effect—The skip

DIRECTION-FINDING LOOP ERRORS

The D/F loop is subject to certain errors, for some of which it is possible to make allowances. Others are variable and unpredictable, and the only precaution the navigator can take is to choose bearings from a direction where errors are less likely to be present and, if this is impossible, to regard any bearings obtained as being subject to confirmation by other means.

COASTAL REFRACTION

One error that can usually be avoided by the wise choice of a transmitter for D/F purposes is coastal refraction. It has been found that wireless waves are subject to refraction, or bending of the wave-path, when crossing a coast line obliquely, or when running

parallel to it. In Fig. 17, the transmissions of Station T, situated on the coast, are being received by a loop aerial in an aircraft at A.

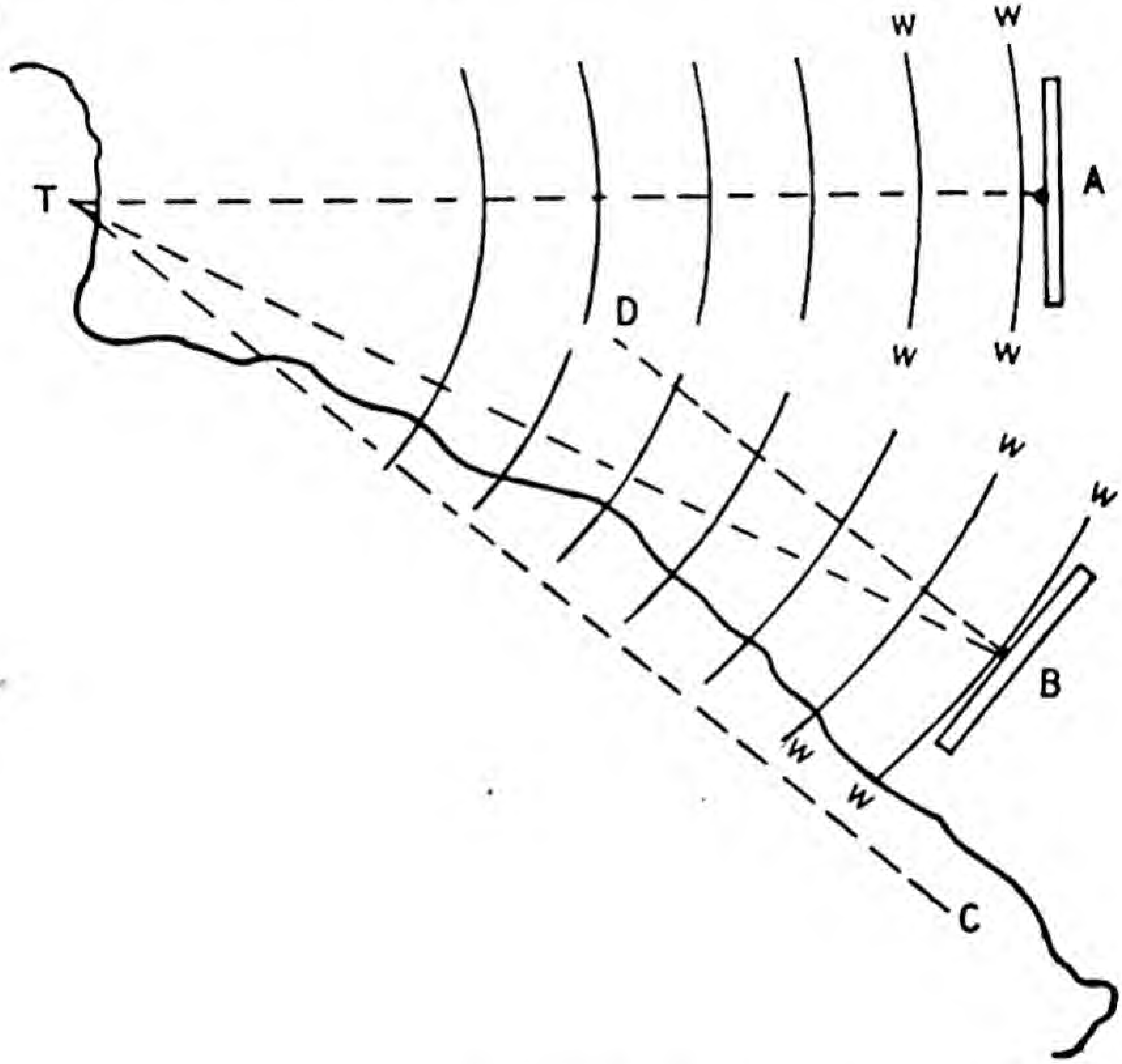


FIGURE 17
COASTAL REFRACTION

The advancing wave front is shown by WW, and it is seen that the loop is parallel to the wave front, so that both sides of the loop are cut by the wave at the same instant. Both sides are at the same potential, and no signals

are heard. The loop is therefore in the minimum position and the loop pointer indicates the position line AT. At position B another aircraft loop is tuned to receive signals from the same station, but it will be noted that the advancing wave front changes its direction just as if the portion of the wave front over the land was retarded or the portion over the sea accelerated. The loop at B is in the minimum position parallel to WW, but the bearing indicated by the loop pointer is not BT, the true bearing, but BD. If a line parallel to BD is now laid off from T in the usual manner, it will give TC as the position line, and will suggest that the aircraft is actually on this line instead of being at B. The error caused by coastal refraction in this case is therefore BTC.

The amount of coastal refraction varies with the angle between the wave-path and the coast, and also with the frequency and the distance. It is seldom above 5°. Similar errors are sometimes caused by mountain ranges.

HEAVY STATIC

During heavy rain, snow or sand-storms, heavy static may be experienced, and this

results in the familiar crackling in the headphones. It also has serious effects on the D/F loop and may produce a wide minimum or indistinct minimum.

ANTENNA EFFECT AND "PICK-UP"

These two errors only concern the installing engineer and the wireless operator, but in passing it may be said that the term "pick-up" refers to the picking up of signals by coils in the actual receiver that have not been adequately screened, and "antenna effect" or vertical error, to an error caused by the two sides of the loop having a different capacity. This can easily be cured by the introduction of a suitable condenser.

QUADRANTAL ERROR

In the early experiments with wireless waves it was found that the waves, which travel at the same speed as light waves, could be reflected like light by metal mirrors. They can also be reflected and re-radiated by metal in other forms, and the metal used in the construction of an aircraft or its engines may thus produce a local electromagnetic

field of sufficient strength to cause errors in the D/F loop. The error caused is known as quadrantal error, and is so named because it is usually zero at fore and aft and athwartships bearings, and at a maximum with quadrantal bearings. It will be noted that the error varies relative to the aircraft's head, and is independent of the compass direction from which the signals are coming.

Electrically it may be compared to the effects produced by two energized coils, one set fore and aft and one athwartships. No provision is made for correcting this error by electrical means, so the error for each aircraft must be calibrated and a table or curve of corrections placed adjacent to the loop scale, in order that the correction may be applied when a bearing is taken.

METHOD OF CALIBRATION

The ideal condition for calibration is when the aircraft is in the flying position, with undercarriage retracted, engines running and all equipment or armament in position. This can only be achieved when actually in the air, but this results in other complications. It is usual, therefore, to calibrate on

the ground in the normal position and to check in the air afterwards.

To carry out the calibration, first choose a transmitter situated some 80 or 100 miles away and known to be transmitting at that time, and find its magnetic bearing from a map. Next place the aircraft well clear of all magnetic material and electric cables. Have the engines running slowly, and all equipment in position. If the heading of the aircraft is to be found by the aircraft's own compasses, these should have been swung before calibration commenced, but owing to the attitude of the aircraft when on the ground these compasses are difficult to read accurately owing to parallax, and it is therefore preferable to find the aircraft's head by means of a landing compass on a tripod. This method also saves the trouble of applying deviation.

With the loop aerial set athwartships, the aircraft should be lined up on the transmitter by means of the landing compass, and in this position the loop, when tuned in, should give an absolute minimum within plus or minus a half degree. See that the scale (or the pointer) is correctly set relative to the loop. The aircraft should now be turned

through 360° in stages of about 20°, the heading in each position measured by the landing compass, and a bearing of the transmitter taken by the loop in each position.

The sum of the loop scale reading and the magnetic heading of the aircraft for each position (less 360°, if necessary) should equal the magnetic bearing of the transmitter, and any difference will be the quadrantal error, thus:

Scale Reading	040°
Magnetic Heading	085°
Loop Bearing	125°
Magnetic Bearing of Transmitter	130°
Quadrantal Error	−5°

therefore the quadrantal correction = + 5°.

If the errors are plotted relative to the aircraft's head, the graph will take the form of a double sine curve and, should this have a definite bias to one side, this error, as distinct from the actual quadrantal error, may be removed by shifting the scale or the scale pointer.

The quadrantal curve that is placed in the aircraft is a correction curve, and is equal

but opposite to the curve of error. In Fig. 18, the centre line (0°–360°) indicates the angle between the aircraft's head and the incoming wave. The correction is measured at right-angles to this line. A table is sometimes used instead of a correction curve, but it is easier

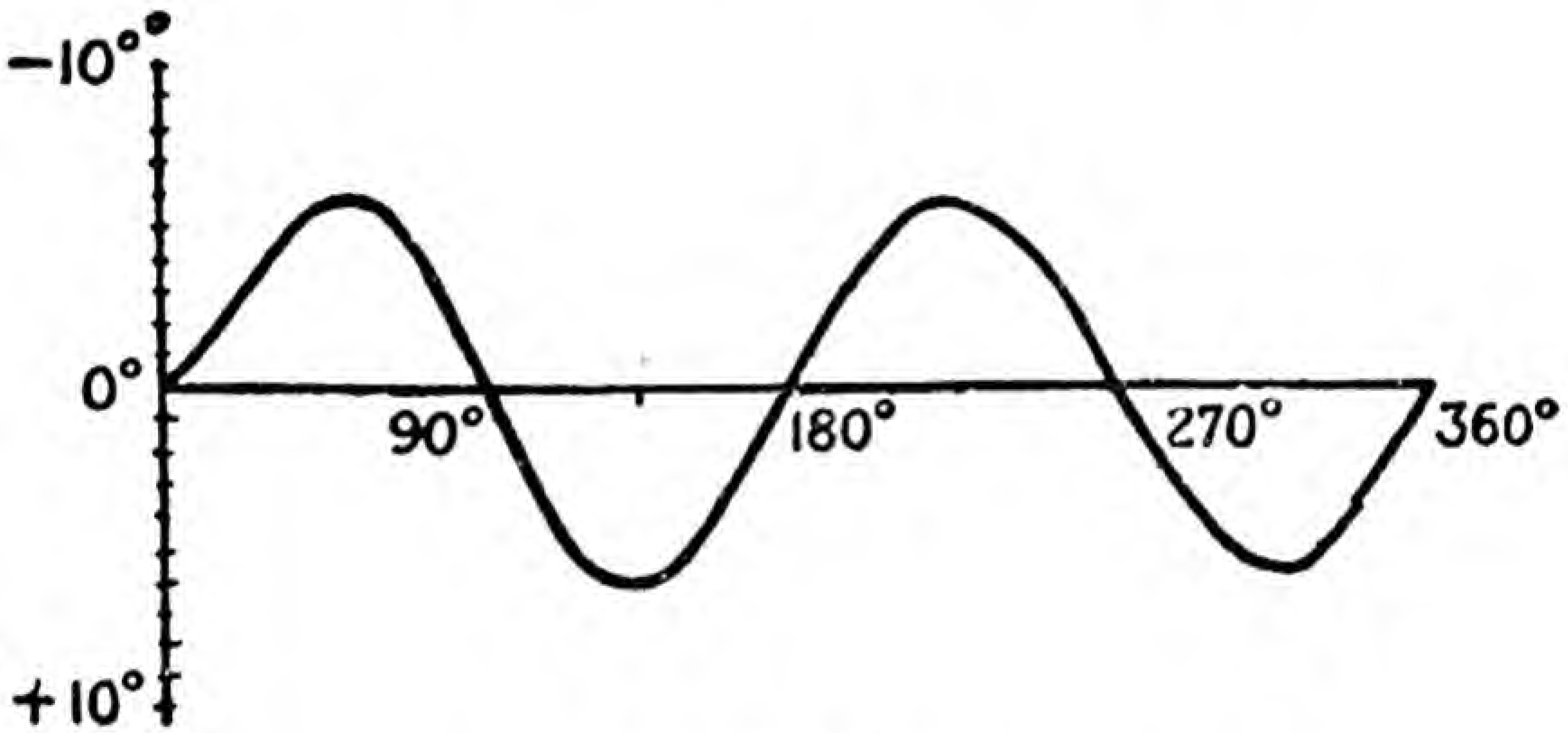


FIGURE 18
QUADRANTAL CORRECTION CURVE

to interpolate with a curve. Quadrantal error should be checked at least every six months, and always after large overhauls or alterations.

NIGHT EFFECT

This error is common to all loop aerials and gives a great deal of trouble. It may be quite large, and is unpredictable. To under-

stand it, one must first consider the variations in the state of the atmosphere. During the day, the atmosphere is subject to solar radiation, and the ultra-violet rays tend to isolate the negative electrons, thus leaving the atoms positively charged. Air in this condition is said to be ionized, and is a partial conductor. Near the earth's surface ionization is least apparent, for two reasons. First, a great deal of the solar energy has been lost in the passage of the ultra-violet rays through the atmosphere, and secondly, the electrons and positive ions re-combine much more readily, owing to the density of the atmosphere near the earth's surface, and the much greater probability of their coming in contact with each other.

There is a level or layer some 50 or 60 miles above the earth's surface, below which there is no appreciable ionization, and this is called the "Heaviside Layer." It will be appreciated that as ionization is caused by solar radiation, its bounds will expand throughout the day and decrease during the night or, in other words, the base of the layer will get lower during the day as ionization takes place, and will get higher at night as the ions and electrons re-combine. This

means that the height of the base of the layer will vary from hour to hour and place to place, according to the relative position of the sun to the earth. Hence there will be few points on the earth where the base is horizontal, and the Heaviside Layer should be visualized as being tilted at a slight angle to the earth beneath it.

Electromagnetic waves are radiated from a transmitter in all directions, those following the earth's surface being called "earth waves" and those travelling upwards "sky waves." These sky waves strike the Heaviside Layer and may be reflected and returned to earth. The downcoming wave is known as the "reflected wave." In visualizing the refraction of the sky wave, one should discard the conventional diagram (Fig. 19) in which the direction of travel of the wave is indicated by a line, and think instead of a wave similar in form to a sea wave. The wave front tilts back slightly and reaches to a great height. As the crest of the wave reaches and penetrates the Heaviside Layer, the refraction causes a re-orientation of the wave front. It is as if a portion of the wave in ionized air accelerated relative to the lower portion, thus causing a pivoting movement of the

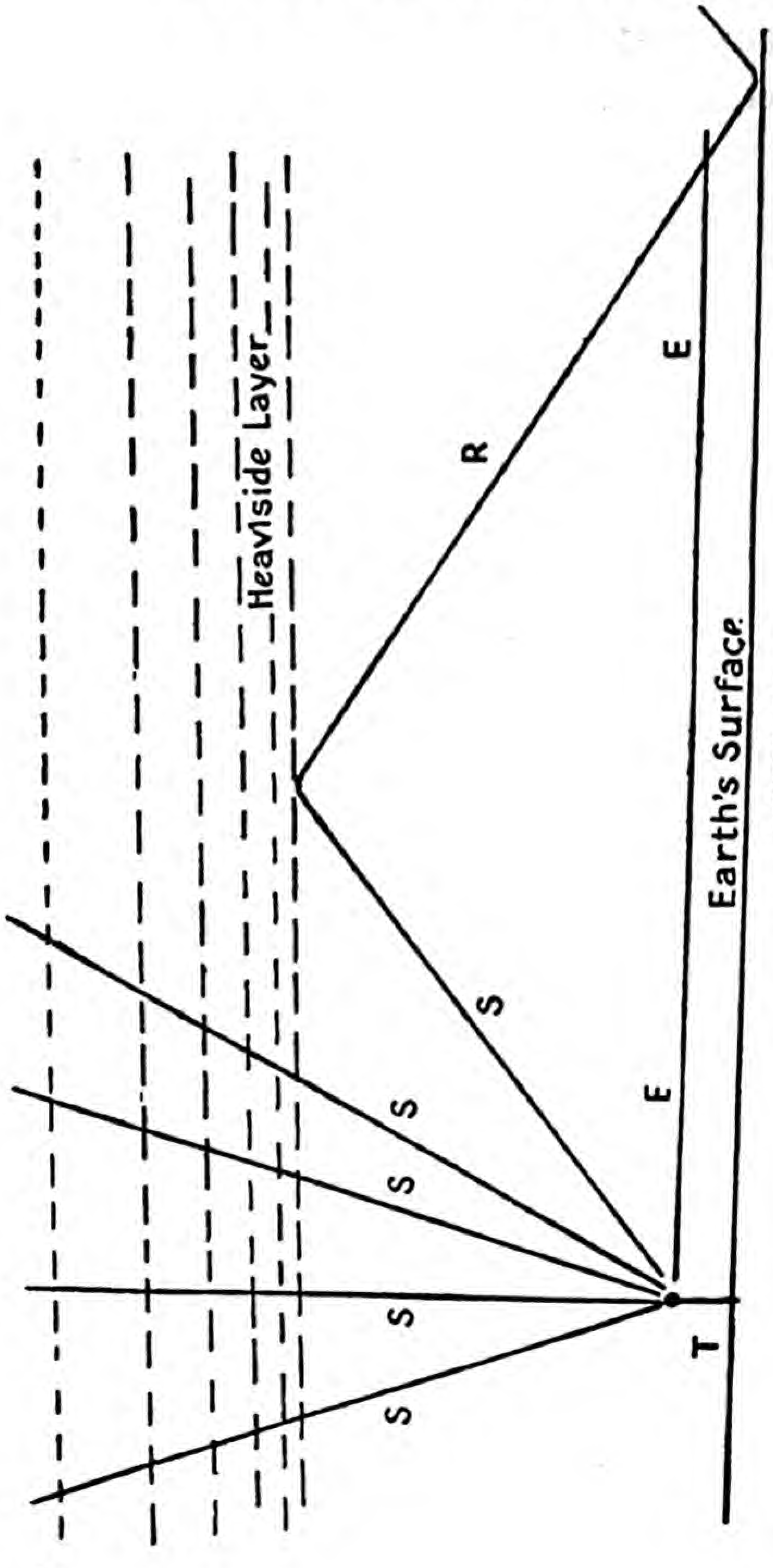


FIGURE 19
THE HEAVISIDE LAYER

wave front about a point moving along the ground.

High frequency waves tend to pass through the Heaviside Layer, and to be reflected by other layers at greater altitudes. With low or medium frequencies the waves may be reflected backwards and forwards between the layer and the earth for great distances, equal in some cases to the circumference of the earth. Fig. 19 shows a transmitter T, the earth wave E, the sky wave S, and the reflected wave R. At some distance from the transmitter it is possible in certain conditions to receive both earth and reflected waves at the same time.

There are three ways in which the reflected waves may cause the error known as "night effect." For the first case, let it be assumed that a loop aerial is in the minimum position, and at right angles to the incoming earth wave. The earth wave will strike the vertical sides of the loop simultaneously, thus causing no current to flow. The sky wave, however, descending obliquely, strikes the *horizontal* portions of the loop successively and induces current. This results in a displaced or indistinct minimum.

Secondly, the sky wave having travelled a

greater distance than the earth wave will be slightly out of phase with it, resulting in fading and indistinct minimum.

Finally, the sky wave may be abnormally polarized by the tilting of the Heaviside Layer. If the layer were horizontal, sky wave and reflected wave would be in the same vertical plane, but when it is tilted there is an angle between the vertical plane of the sky wave and the vertical plane of the reflected wave. The reflected wave is therefore at an angle to the earth wave, and the loop minimum will be at that point where the effects of the earth and reflected waves cancel out.

The error from these causes may amount to 20° or more, and may be increased by sunspots, electrical storms or seasonal causes.

Although called "night effect," the error is greatest within about one hour of sunset or sunrise. Returning to Fig. 19, it will be seen that only the more oblique waves are reflected, the others passing through the ionized layer.

This is particularly noticeable with high frequency waves, which penetrate the layer much more readily. Moreover, the refractive index for any substance varies for different

wave lengths so that a wide range of effects may be obtained by varying the frequency or the angle of incidence.

THE SKIP

Most direction finding is carried out on the medium wave length, the effective working range varying with the latitude, the time of day, the type of apparatus, and other factors. Owing to the deionization of the air at ground level at night time, wireless waves are less liable to absorption, and in consequence D/F bearings can be taken at greater distances at night.

There is a modern tendency towards long range bearings of 300 miles and upwards, and for this purpose short wave, high frequency sets are used.

With high frequency D/F, the earth wave has a short range of less than 100 miles, and the receiver works on the reflected wave only, for greater distances. It has been mentioned that only those sky waves which strike the Heaviside Layer obliquely are reflected, so the receiver must be at a considerable distance from the transmitter before the reflected wave can be picked up. In Fig. 20,

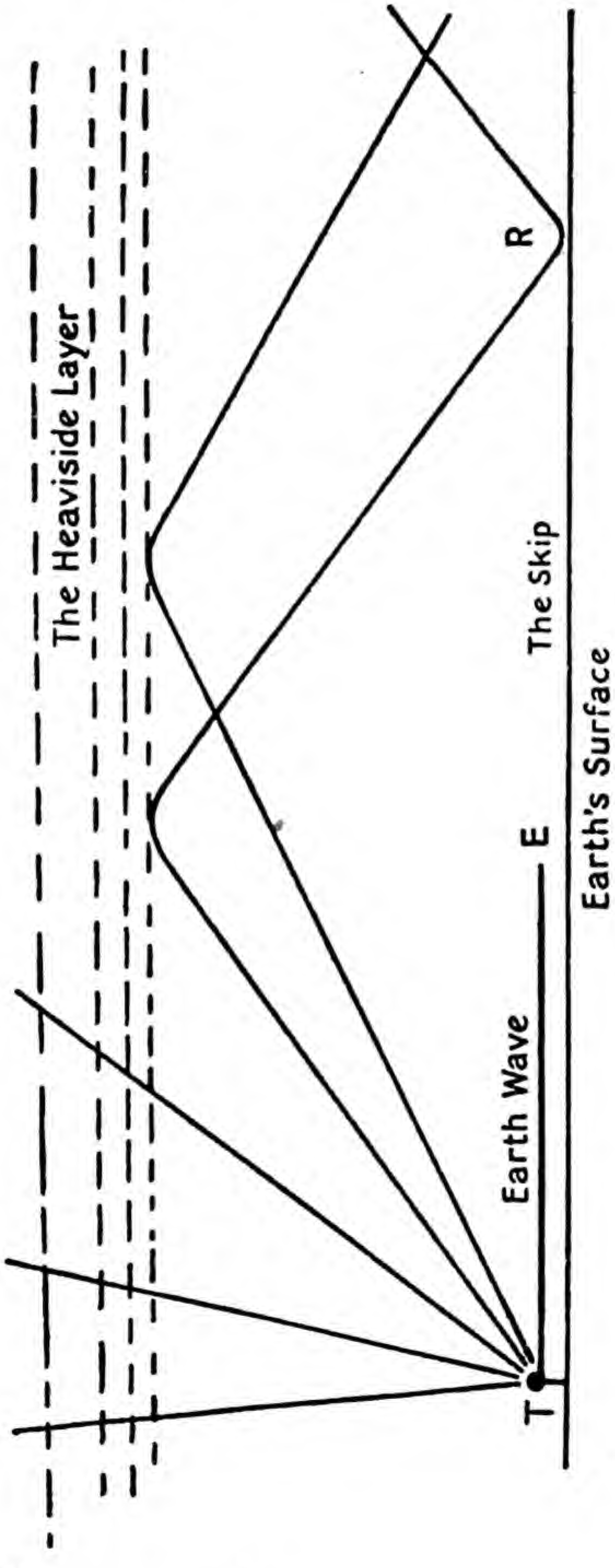


FIGURE 20

SHORT WAVE DIRECTION-FINDING

it will be seen that the earth wave terminates at E, and the reflected wave is picked up at R. The space between E and R is known as the "skip" or skip distance, and in this space no signals will be received. As the base of the Heaviside Layer rises at night, the "skip" becomes wider, and may cover a hundred miles or more.

CHAPTER IV

Plotting—Short range loop bearings—Medium range loop bearings—Convergency—Conversion—Long range loop bearings—Advantages of the loop—"Homing"

PLOTTING

When the wireless operator has taken the bearing, he hands the navigator a card carrying the name of the transmitter, its frequency, the scale reading, the exact time it was taken, and the class of the bearing. Bearings are divided into three classes, according to their reliability, and the operator is responsible for deciding to which class they belong.

When the navigator receives the bearing, he must first of all apply the true course to the scale reading, in order to find the true bearing. One bearing alone will not, of course, fix the aircraft's position, but will only give a position line, somewhere on which the aircraft is supposed to be situated. If, however, two or more bearings are avail-

able, the intersection of the position lines will indicate the position of the aircraft at the time the bearings were taken. This is known as a "fix".

SHORT RANGE LOOP BEARINGS

Except in very high latitudes, short range bearings up to 50 or 60 miles range may be plotted as if they were visual bearings. As an example, consider the following case:

An aircraft whose *approximate* position is in latitude 53°30′ N., longitude 00°30′ W., is steering 030° true when simultaneous loop bearings of transmitters A and B are taken.

STATION "A"		STATION "B"	
Scale Reading	270°	Scale Reading	225°
True Course	030°	True Course	030°
True Bearing	300°	True Bearing	255°

It has now been found that Stations A and B bear 300° and 255° respectively from the aircraft, but the aircraft's position is in doubt, so the reciprocal of these bearings must be laid off from Stations A and B, the positions of which are known; 300° less 180° gives the

first reciprocal as 120°, and this is laid off from A (Fig. 21). The reciprocal of the second bearing (075°) is laid off from B, and the point of intersection of the two bearings or position lines at C is the position of the

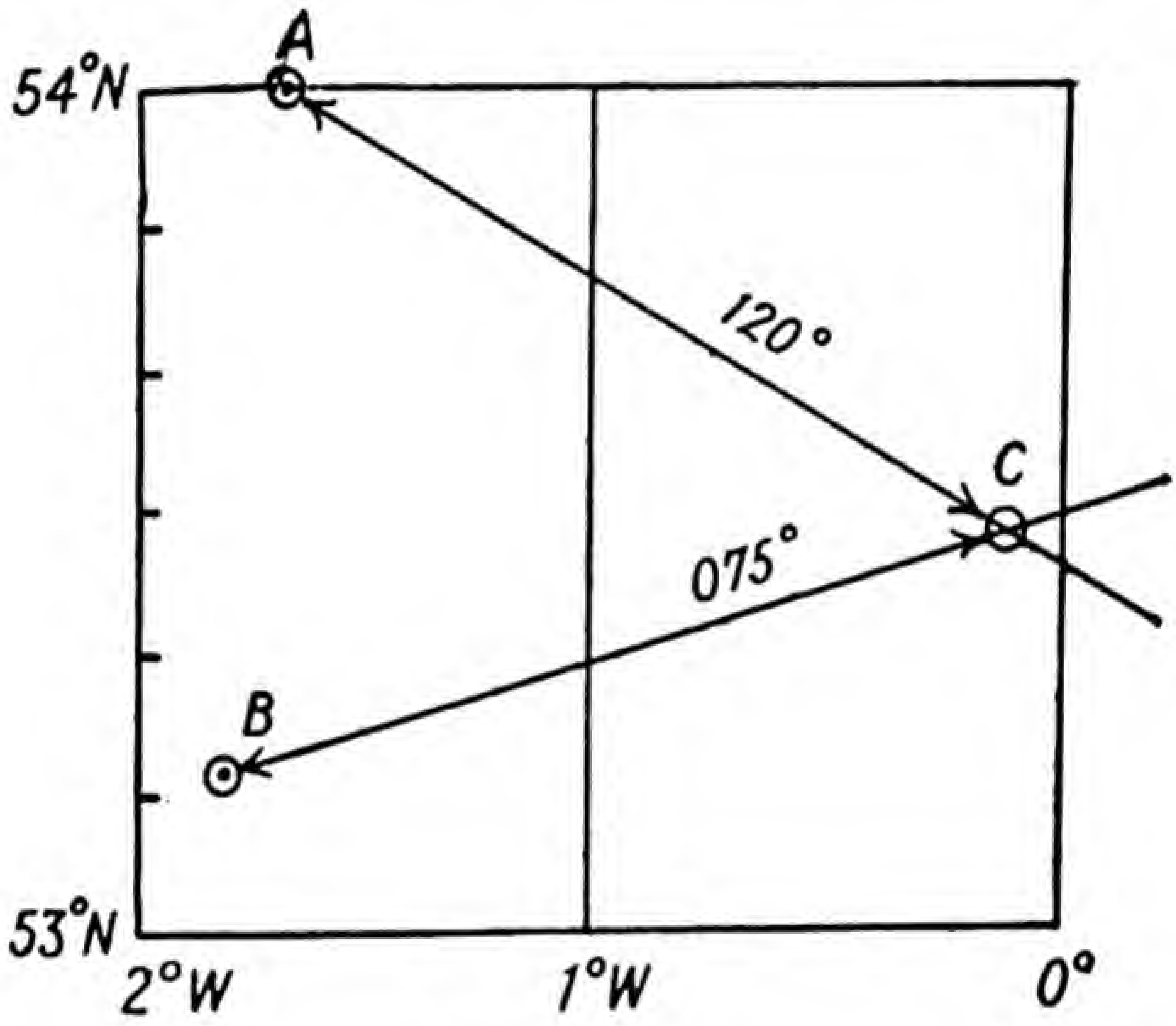


FIGURE 21

FIX BY SIMULTANEOUS BEARINGS

aircraft at the time the bearings were taken.

If only one radio bearing is available, it may be plotted in conjunction with visual or astronomical position lines, in order to get a fix, or alternatively it may be carried along the aircraft's track until such time as another bearing can be taken. This method

is described under the heading of "Running Fixes" in the *Observer's Handbook on Dead Reckoning Navigation.*

MEDIUM RANGE LOOP BEARINGS

Before discussing the methods of plotting medium range bearings, that is, bearings covering 300 miles or less, it is necessary to consider the properties of maps based on different projections. For the purposes of Radio Navigation, maps may be divided into two classes, those on which a straight line is approximately the arc of a great circle, and those on which a straight line is a rhumb line. A great circle is a circle on the surface of a sphere, whose plane passes through the centre of the sphere. The shortest distance between any two points on the earth's surface is always along the shorter arc of the great circle passing through the two points. The equator is a great circle, and the meridians are semi-great circles, but in both these cases they are also rhumb lines. Rhumb lines are lines which cut each meridian they meet at the same angle. All great circles other than the above cut each meridian they meet at a slightly different angle.

The majority of aeronautical maps in general use, including the modified polyconic, Cassini's, the Conical Orthomorphic, and the Gnomonic, show arcs of great circles as straight lines, with a reasonable degree of accuracy, and this simplifies plotting of D/F bearings, as wireless waves travel over the earth's surface along the arcs of great circles.

When a bearing is taken *from* an aircraft in a certain longitude, its reciprocal must be laid off from a W/T station in a different longitude, and allowance must be made for the convergency of the meridians, as the bearing was measured relative to one meridian but must be laid off relative to another meridian, which is not parallel to the first.

CONVERGENCY

If we look at a globe, we find that the meridians meet at the pole, and that the angle between two adjacent meridians is 1°. In other words, 1° of longitude = 1° of convergency. At the equator, the meridians are at right angles to the equator and there is, therefore, no convergency. In all other latitudes convergency may be found by means

of tables, by plotting, the use of a diagram or "ABAC" or by the formula:

"Convergency = change of longitude X the sine of the middle latitude." To find

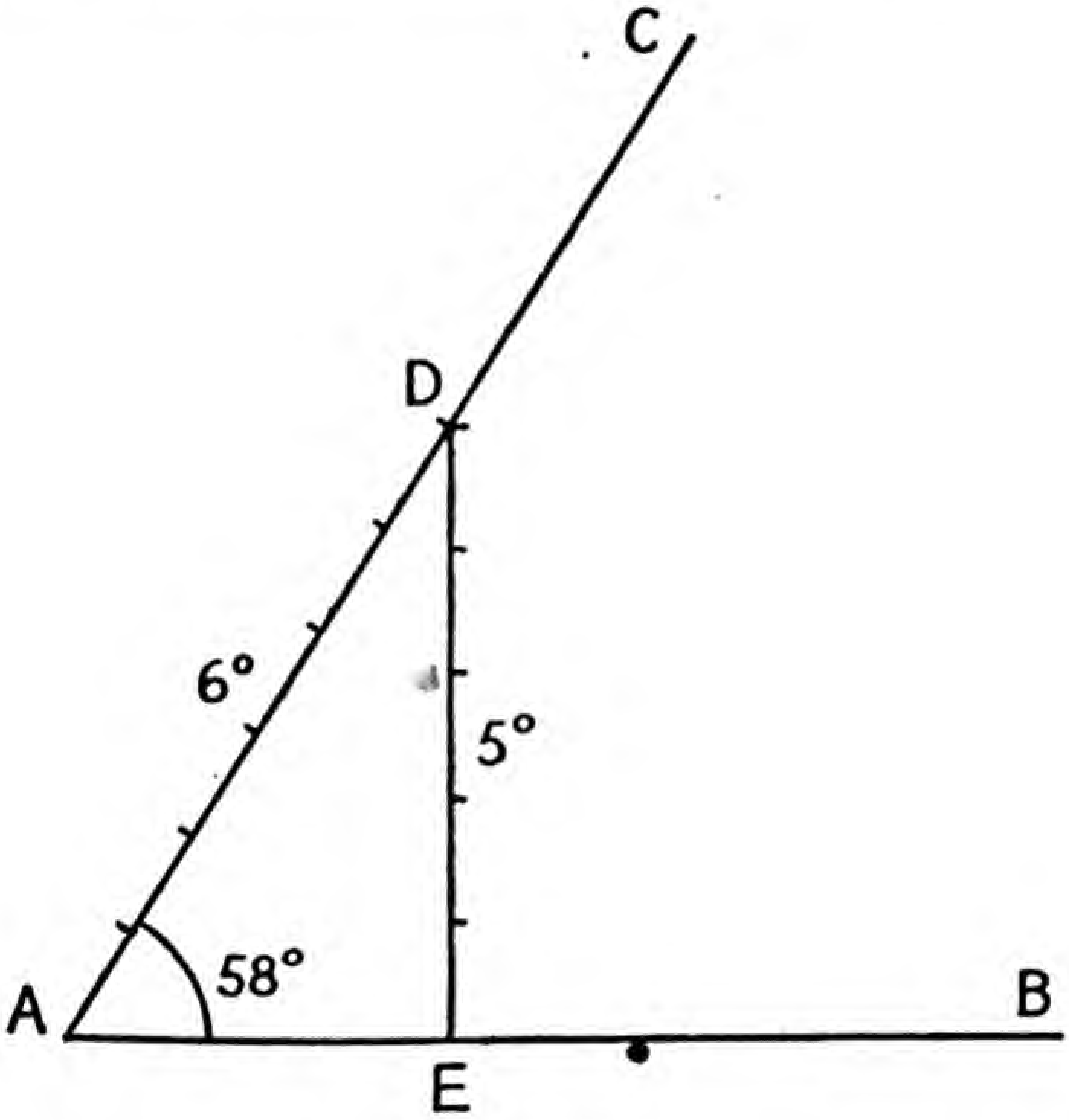


FIGURE 22
CONVERGENCY

convergency by means of a diagram (Fig. 22), draw a base line AB and from A lay off AC at an angle to the base equal to the middle or mean latitude of the aircraft and the transmitter, say 58°. Along the line AC mark off, to any suitable scale, the number of

units equal to the difference or change of longitude between the aircraft and the transmitter, say 6°. Let the point found be called D. From D, drop a line perpendicular to the base line, and the length of this line, to the same scale as before, gives the convergency in degrees, in this case 5°.

Many plotting maps carry an "ABAC" for finding convergency (or conversion), and this device consists of three vertical parallel lines; the two outside lines are divided to represent change of longitude and middle latitude respectively, and the middle to represent convergency. To find the convergency, it is only necessary to draw a straight line from the appropriate change of longitude on the left-hand line to the middle latitude on the right-hand line, and it will be found to cut the centre line at the correct convergency.

Fig. 23 shows a section of a map based on a conical projection, that is, one on which the meridians converge towards the pole. An aircraft A has taken a bearing of a transmitter T, and the true bearing is 268°. The *approximate* position of the aircraft is in latitude 58° N., longitude 24° E., and it is therefore relative to the twenty-fourth meridian

that the bearing has been taken. It must, however, be laid off from the position of the transmitter, which is in longitude 18° E., and the eighteenth and twenty-fourth meri-

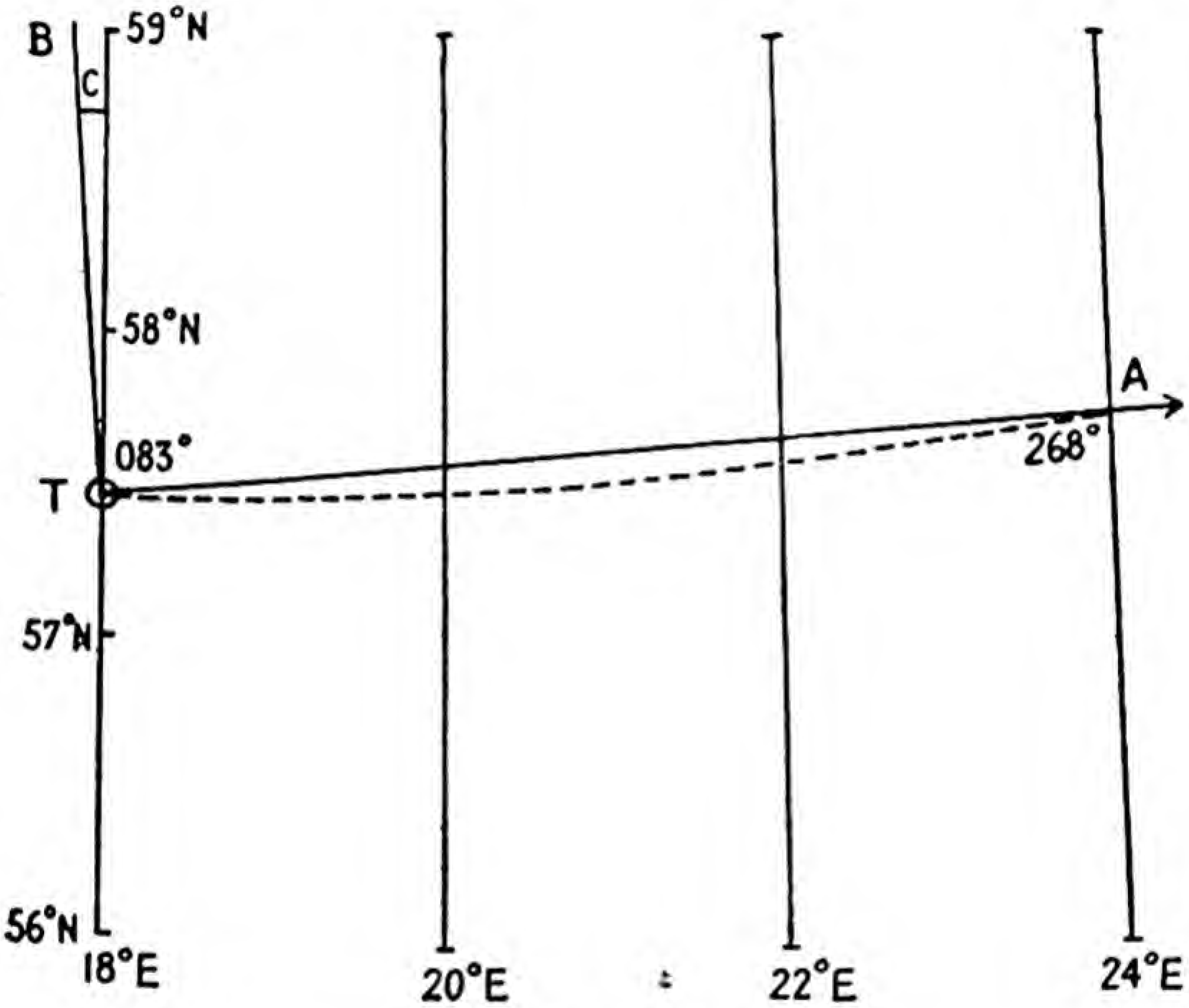


FIGURE 23

GREAT CIRCLE BEARING

dians are not parallel, as may be seen by drawing a line from T parallel to the twenty-fourth meridian (TB). The angle C is the convergency.

The convergency for this bearing has already been found in Fig. 22 to be 5°, and

it must be applied in the following manner:

True Bearing	268°
Convergency	5°
	263°
	180°
Reciprocal	083°

NOTE.—The convergency is always applied towards the equator.

If the reciprocal is now laid off from the transmitter, it will give TA, extended, if necessary, as the position line on which the aircraft is situated. A second position line, preferably at a large angle to the first, will enable a fix to be made. One position line alone may be useful as a check on either track or ground speed, according to whether it has been taken from ahead or astern of the aircraft, or from one side.

It should be noted that the line TA is the arc of a great circle and cuts each meridian at a different angle. A rhumb line track from T to A would follow the broken line, which cuts each meridian at the same angle. The rhumb line is always on the equatorial side of the great circle.

Convergency must be applied to all

medium range loop bearings that are to be plotted on maps other than Mercator's.

CONVERSION

Conversion must be applied to all medium range radio bearings laid off on a Mercator's

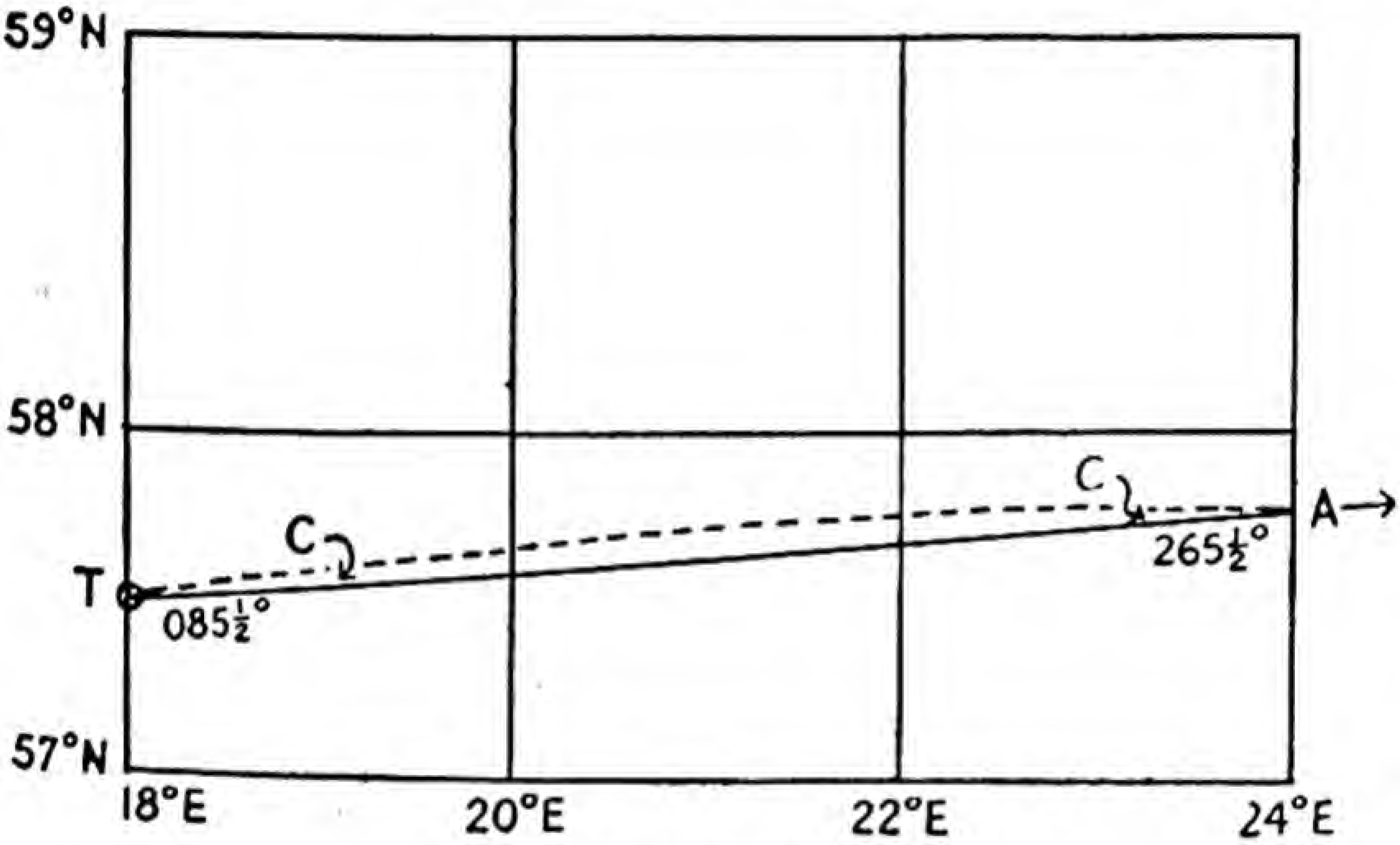


FIGURE 24

MERCATORIAL BEARING

map or chart. The conversion angle is half the convergency and may therefore be found by similar methods. It is applied in the same manner, that is, towards the equator. Fig. 24 shows a section of a Mercator's map, and it will be seen that the meridians, which on other projections converge, have been opened out and are now parallel straight lines. In

consequence, rhumb lines, which on other projections are curves, appear as straight lines, while arcs of great circles previously shown as straight lines are now curves convex towards the nearest pole.

If the bearing of 268° which was laid off in Fig. 23 is now to be laid off on Mercator's as in Fig. 24, the method is as follows:

True Bearing	268°	
Conversion Angle	2½°	(Approximately)
Mercatorial Bearing	265½°	
	180°	
Reciprocal	085½°	

The reciprocal 085½° is laid off from T, giving TA as the position line. The great circle bearing is indicated by the broken line and the conversion angle, which is the angle between the great circle and the rhumb line, by the letters CC.

It will be observed that with a conversion angle of 2½° the two bearings are nowhere very far apart, and so in practice it is as well to ignore conversion angles of less than 2°, as the resulting error will be negligible unless the aircraft is in tropical latitudes.

Both conversion and convergency are at a maximum in high latitudes, and when the bearing is nearly at right angles to the meridians.

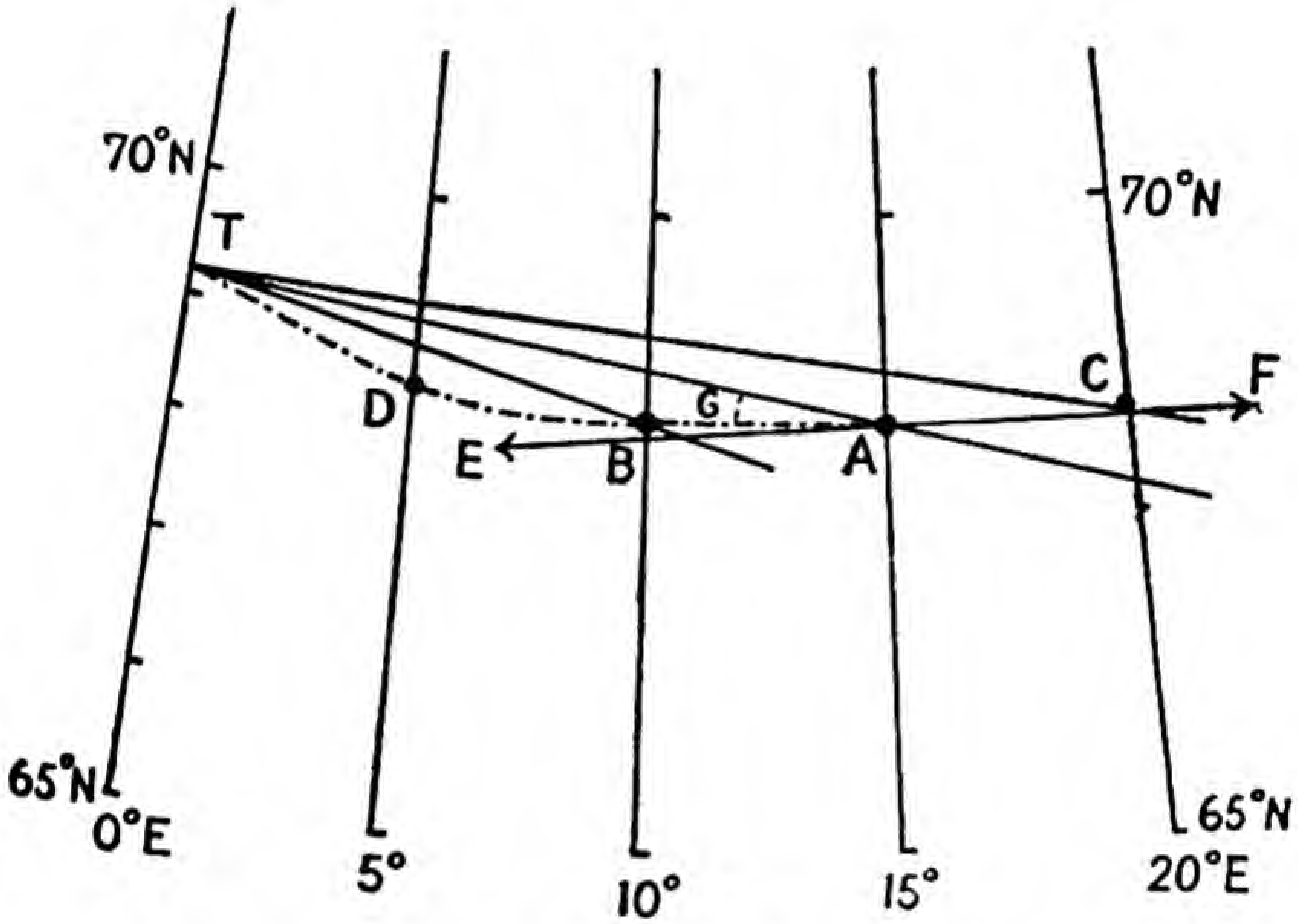


FIGURE 25

LONG RANGE BEARING. CONIC PROJECTION

LONG RANGE LOOP BEARINGS

Maps other than Mercator's

When taking long range bearings or bearings in high latitudes, consideration must be given to errors which may be ignored with medium or short range bearings. In the example illustrated by Fig. 25, it is assumed

that an aircraft has been flying on dead reckoning for some hours and that the error in its estimated position may amount to a hundred miles or more. A loop bearing of say 287° is taken of a W/T station in latitude 69°10′ N., longitude 00°00′. The dead reckoning position of the aircraft is latitude 68° N., longitude 15° E. Thus the middle latitude is about 68½° N., and the change of longitude 15°. The convergency comes to approximately 14°.

True Bearing	287°
Convergency	14°
	273°
	180°
Reciprocal	093°

The reciprocal is laid off from T, the transmitter, giving TA as the great circle bearing. If the D/R longitude was correct, then the aircraft is at the point where the position line cuts the meridian of 15° E., i.e. it is at A.

Now let us assume that the estimated position is seriously in error, and plot position lines for two other possible positions, "B" in

longitude 10° E., and "C" in longitude 20° E.

POSITION "B"		POSITION "C"	
True Bearing	287°	True Bearing	287°
Convergency	9°	Convergency	18°
	278°		269°
	180°		180°
Reciprocal	098°	Reciprocal	089°

The reciprocals to be laid off from T are 098° (TB) and 089° (TC), and it is noticeable that both positions are about 20 miles off the original position line TA. The same bearing has been plotted for A, B, and C, so a line or curve joining them may be called a line of equal bearing. If the full curve between T and A is plotted, it will follow the dotted line TDBA.

This curve of equal bearing is obviously a more accurate position line than the line TA, but the process of plotting a series of positions and drawing a curve is too laborious and slow to be practicable. If, however, a tangent to the curve BA is laid off (EAF) it will be found to make an angle with the line TA approximately equal to the convergency (G). This line passes quite close to

the alternative positions B and C, and is therefore reasonably accurate as a position line.

The actual procedure of plotting bearings of this sort is to assume a position, calculate the convergency, apply it to the true bearing, then take the reciprocal and lay it off from the transmitter. At the point where the line cuts the assumed longitude, lay off an angle equal to the convergency, and the line found —extended as necessary—will be the position line.

It should be remembered that the curve of equal bearing is always concave towards the nearest pole.

The above procedure should be followed when the convergency amounts to 8° or more, and when the bearing is to be laid off on a map other than Mercator's, as may be the case with a flying boat operating in high latitudes, where Mercator's maps are not suitable because of the rapid change of scale.

Mercator's Maps and Charts

Owing to the great navigational advantages of Mercator's maps and the complications caused by plotting on several maps at the same time, it is usual in moderate

latitudes to plot long range bearings on a Mercator's plotting map, in spite of the fact that the paths of wireless waves appear as curves. The method of plotting the same

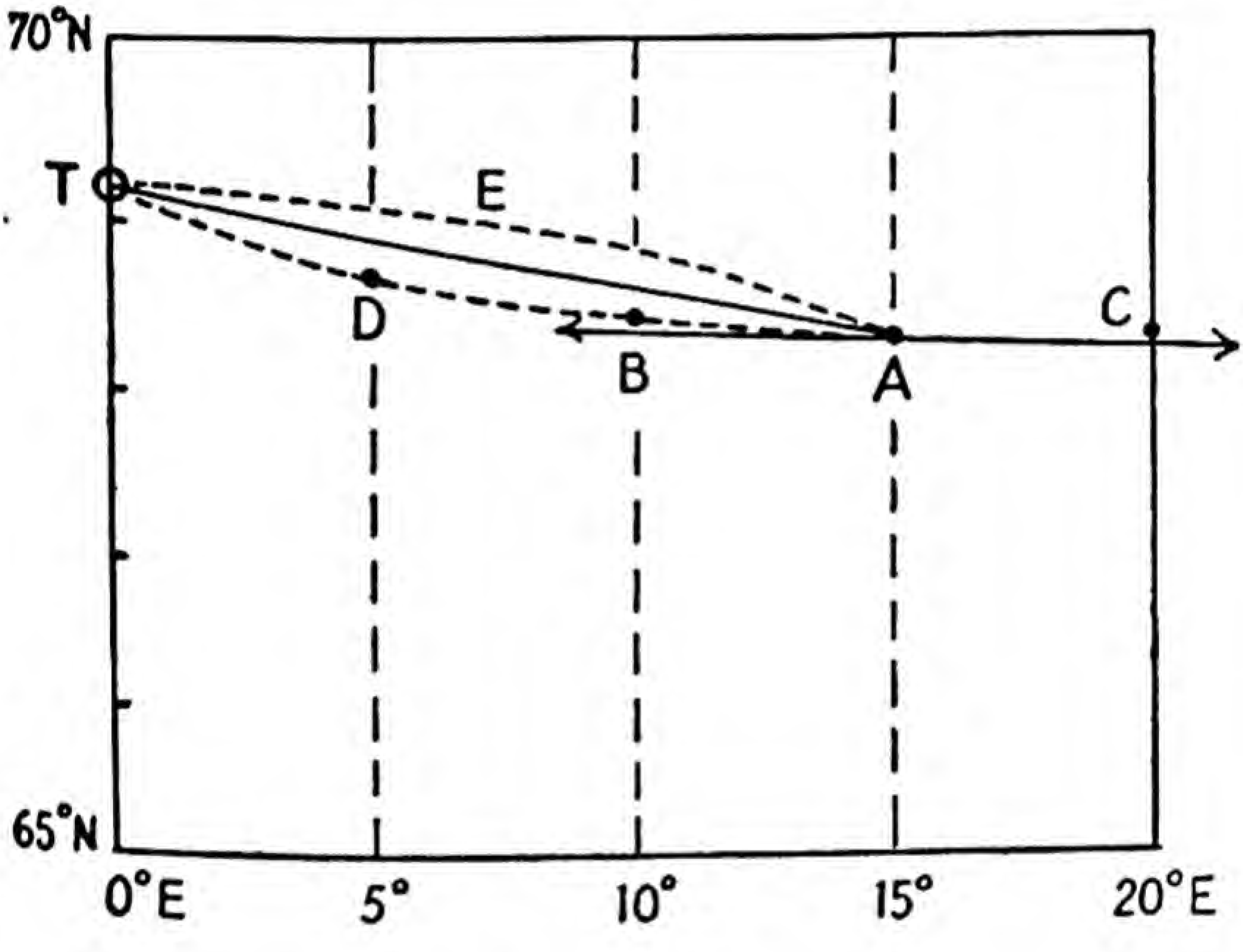


FIGURE 26

LONG RANGE BEARING. MERCATOR'S PROJECTION

bearing used in the last figure, but on a Mercator's map, is shown in Fig. 26.

The *assumed* position of the aircraft is in latitude 68° N., longitude 15° E., which gives a conversion angle relative to transmitter T of 7°.

True Bearing	287°
Conversion	7°
	280°
	180°
Reciprocal	100°

The rhumb line or mercatorial bearing of 100° is laid off from T and crosses longitude 15° E at A, which must be the position of the aircraft if the assumed longitude is correct. If, on the other hand, the correct longitude were 10° E. or 20° E., then the conversion angle would be approximately $4\frac{1}{2}$° or 9°, and the aircraft at points B or C, which are on the curve of equal bearing.

To obtain the position line, the rhumb line bearing for position A should therefore be plotted, giving TA, and at the point A where it crosses the meridian of the assumed longitude the conversion angle should be laid off as a tangent to the curve of equal bearing. This, then, is the position line and it will be noted that it passes close to positions B and C. Thus no great error is involved even if the assumed longitude is seriously in error.

The great circle bearing (E) for position

A has been drawn in on the polar side of the rhumb line and it will be seen that it is symmetrical about the rhumb line to the curve of equal bearing, which is represented by the broken line TDBA. The great circle bearing is always on the polar side and the curve of equal bearing on the equatorial side. A tangent to the curve of equal bearing should always be plotted when the conversion angle exceeds about 4°.

For important flights, when it is known beforehand that certain transmitters will be used for loop bearings, a special map may be prepared with a series of curves of equal bearing plotted for each transmitter. Fixes may then be plotted with great ease.

ADVANTAGES OF THE LOOP

The main advantages of the loop aerial are that any transmitter whose position is known can be used for bearings, and the aircraft does not disclose its position when taking bearings. Moreover, a number of aircraft can take bearings of the same station without interfering with each other.

Its disadvantages are its liability to night effect and other errors, its relatively short

range under most conditions, and the fact that unknown errors of the aircraft's compass may be included in any bearing taken. In addition it is necessary for the aircraft to carry special equipment and a trained wireless operator.

In war time special measures are taken to prevent aircraft using ordinary broadcasting stations for direction finding purposes, and most direction finding is done with the aid of mobile transmitters whose position can be changed from day to day.

"HOMING"

The term "homing" means flying towards a particular wireless transmitter with the aid of the aircraft's direction finding equipment. At one time it was customary to instal a large-diameter fixed loop in the aircraft for this purpose, but this practice has been rendered obsolete by the rotating loop. If the rotating loop is set exactly athwartships and tuned to receive a particular station, then the position of minimum signals will be with the transmitter exactly ahead or astern, and the aircraft should therefore be turned until the minimum is heard. The

aircraft will then be heading directly towards or away from the transmitter. The sense of the bearing is obtained in the usual way and, if necessary, the aircraft is turned through 180° so that it is heading for the transmitter.

The aircraft will fly on a straight path to the transmitter if there is no wind, but this is seldom the case. Fig. 27 shows an aircraft at A heading towards a transmitter T. There is a beam wind W which carries the aircraft in the direction of B. At this point the aircraft is again turned towards the transmitter, and a similar procedure takes place at points C and D. It will be noted that in each case the aircraft turns more into the wind, so that it finally approaches the transmitter up-wind. If the pilot has no knowledge of the amount of drift and of his distance from the transmitter, a fairly accurate course may be set by altering course by an amount equal to three times the change of bearing. Assuming that the aircraft is heading for the transmitter, the compass course is noted and held for a short period, during which the aircraft will have drifted from the desired track. The aircraft is then turned until minimum signals are heard, and the new course is noted.

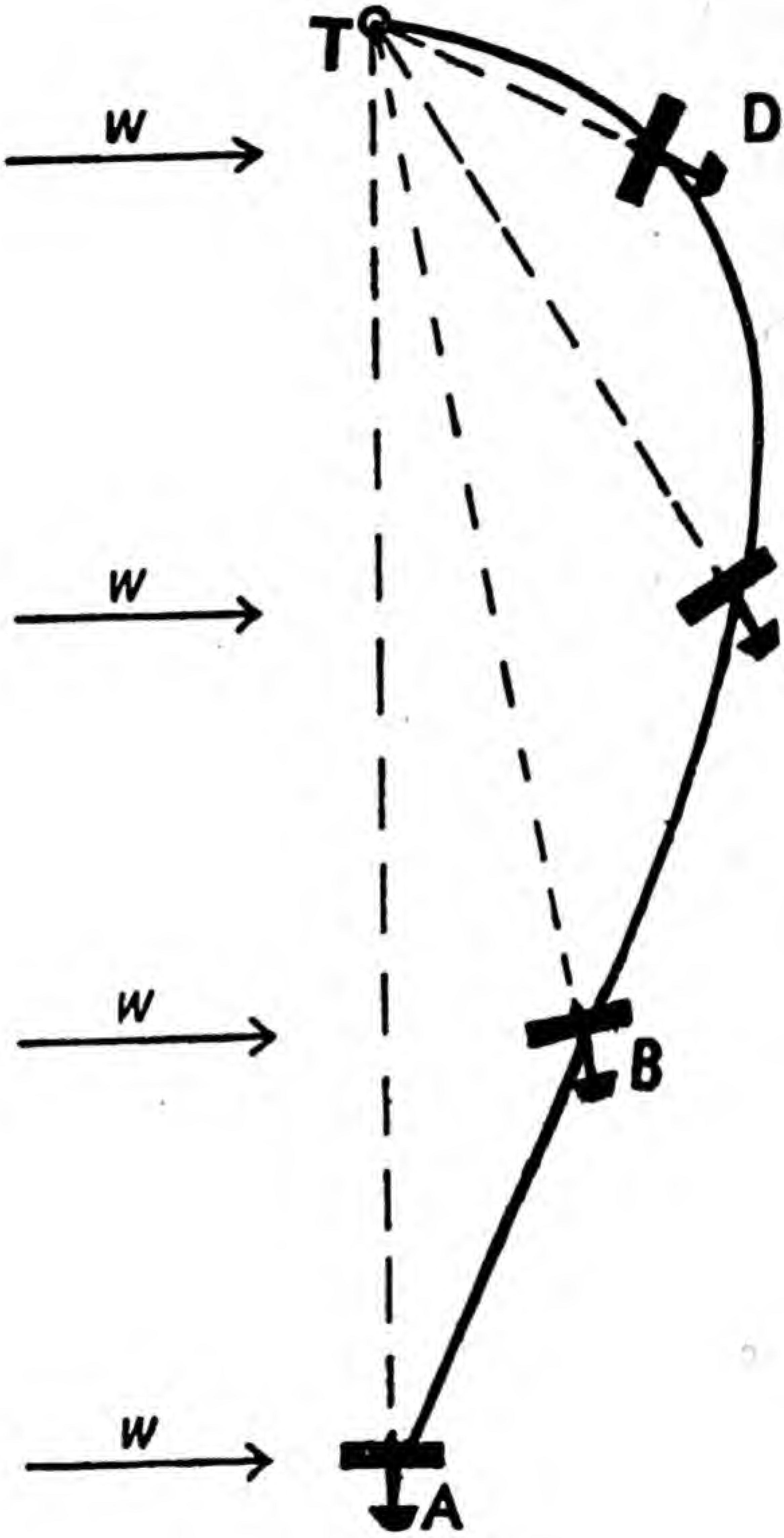


FIGURE 27
"HOMING"

A further turn in the same direction but of three times the amount should now be made. It may be necessary to repeat this manœuvre two or three times.

If the drift of the aircraft is known, the loop may be turned through the angle of drift and the aircraft will then fly on the direct path to the transmitter, if the minimum signals position is maintained. In Fig. 28 the aircraft A is flying towards the transmitter T, and the direction of the wind is indicated by the arrow W. The aircraft is drifting 23° to starboard, and the loop aerial L has been set 23° to starboard, so that it is only necessary for the minimum signals position to be maintained for the aircraft to keep the correct course AC in order to follow the desired track AT.

One disadvantage of using a loop aerial in this manner is that the transmitter may cease transmitting, and it may be some time before it is noticed. If, however, the loop aerial is linked with the trailing aerial by means of a change-over switch, signals will be heard continuously, and if the switch is frequently operated, either by hand or automatically, the correct heading of the aircraft will be that in which operation of the switch

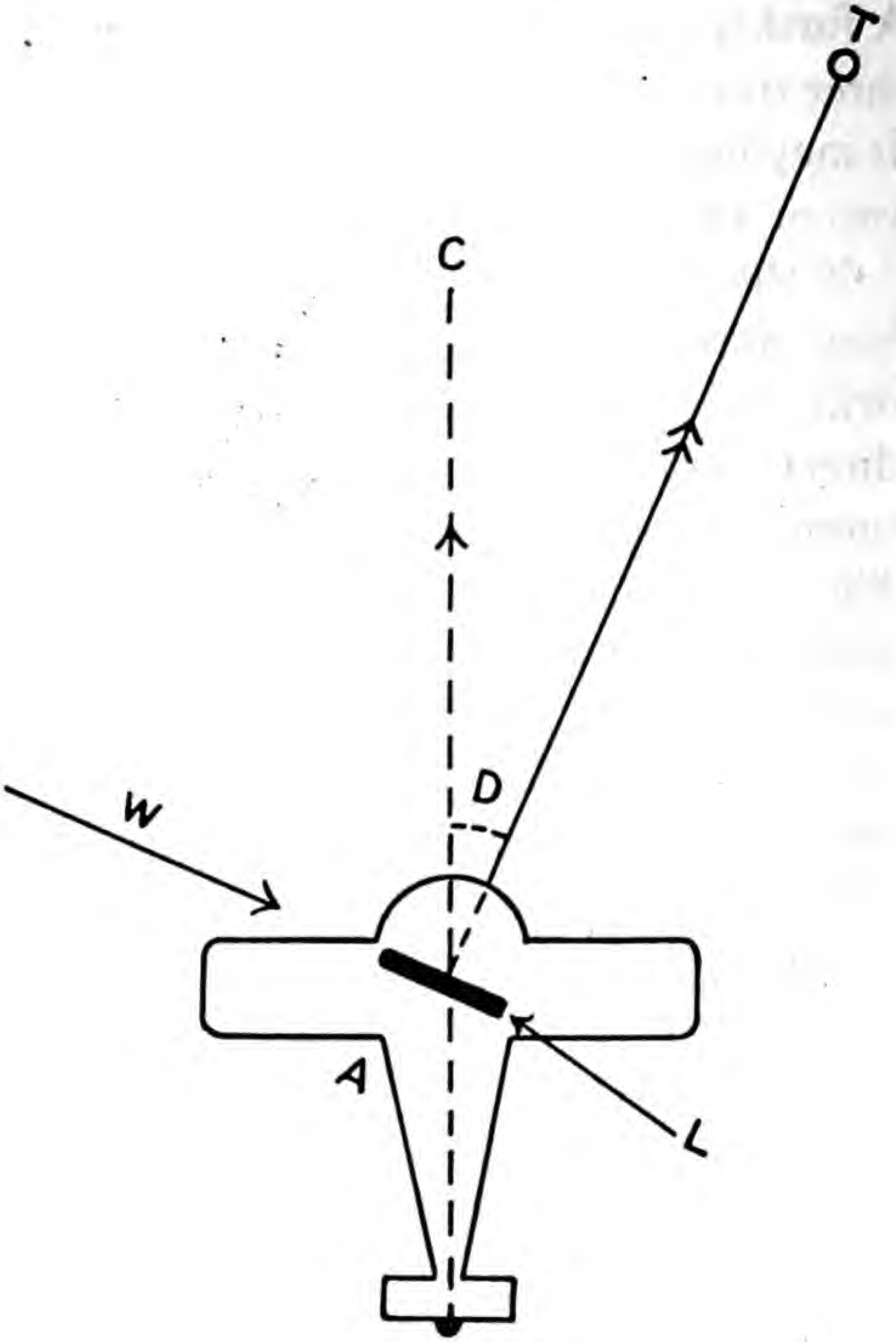


FIGURE 28
DIRECT "HOMING"

produces no change of volume, because the loop is then in the minimum position and neither increases nor decreases the volume

of signals from the trailing aerial. With some modern equipment, notably the apparatus which is known in America as the "Radio Compass," it is possible to home by means of a visual indicator, with which it is only necessary to keep the pointer on the centre of the scale in order to fly towards the transmitter. The system may also include a loud speaker, in which case sense may be determined by the gradual increase or decrease of volume as the aircraft flies towards or away from the transmitter.

CHAPTER V

Ground D/F stations—The Bellini-Tosi system —The Marconi-Adcock system—Plotting

GROUND D/F STATIONS

From the point of view of the navigator the use of ground D/F stations offers little difficulty, nor is it necessary for him to know very much about the apparatus used, providing he has a good knowledge of the limitations of the system. Ground stations usually work in threes, a control station and two subsidiaries. An aircraft which wishes to know its position calls up the control station which in turn notifies the subsidiary stations. The aircraft then operates its transmitter for a short period, enabling all three stations to take bearings of it. The bearings are then plotted by the control station and the aircraft is informed of its position. It should be noted that the aircraft needs only the ordinary transmitter and receiver to make use of this service, but in war time the system has the disadvantage of disclosing

the aircraft's position. Moreover, only one aircraft can be dealt with at a time, and this may result in serious delays.

THE BELLINI-TOSI SYSTEM

The apparatus in use at the ground station is based on the original "Bellini-Tosi" equipment. Of course, bearings could be taken with the aid of an ordinary rotating loop, but if this were made large enough to give very long range it would be cumbersome and slow in operation. The Bellini-Tosi system overcomes this difficulty by the use of two large fixed triangular loops, set North-South and East-West respectively, which are coupled to two small coils in the receiving set. These two coils, which have many turns, are set at right angles to each other in a similar manner to the triangular loops to which they are connected (Fig. 29). This part of the receiving apparatus is known as a "Radio Goniometer."

An incoming wireless wave sets up an electro-magnetic field round the loop aerials and induces currents in them. These currents flow through the two internal coils which, owing to their small diameter and relatively

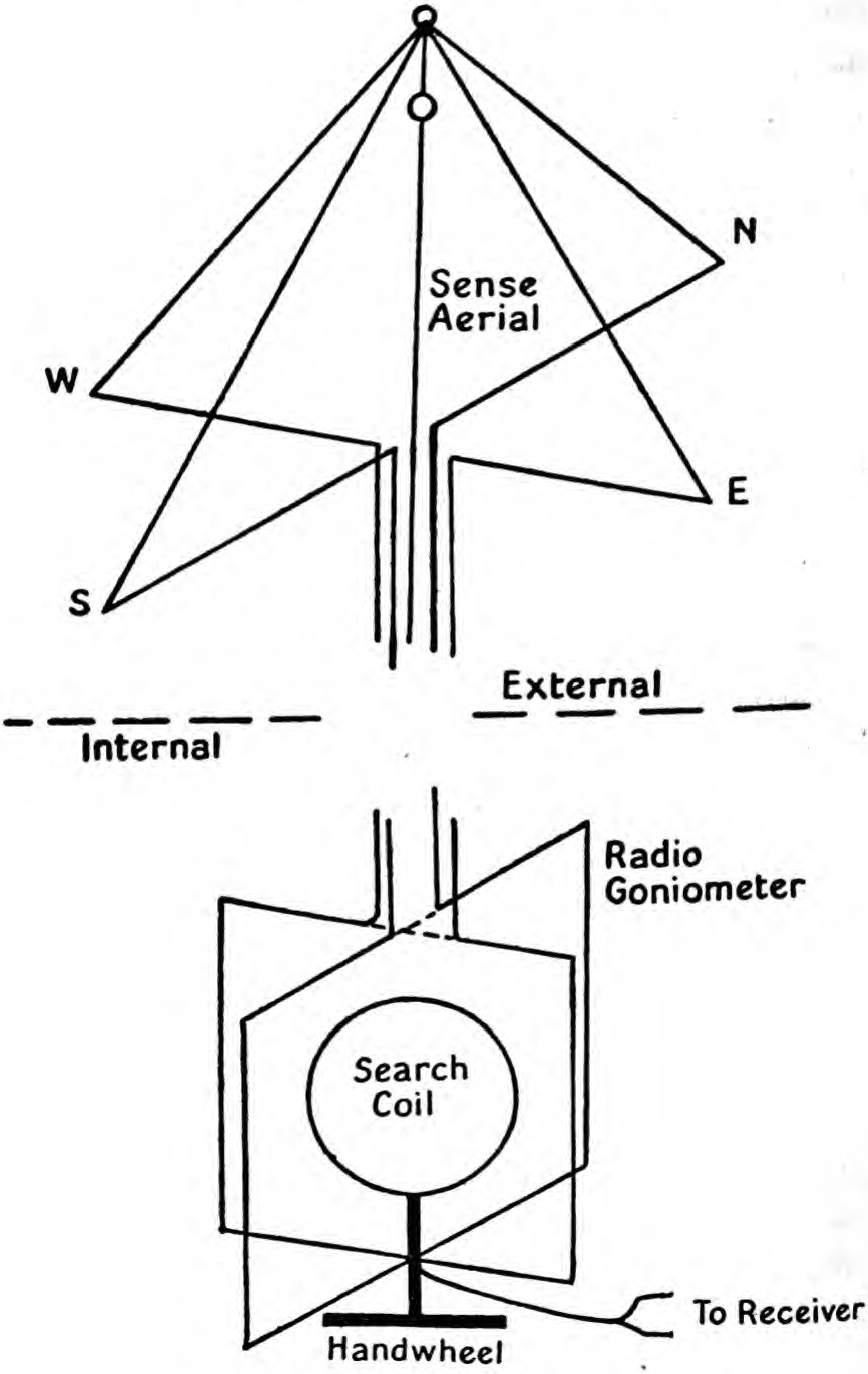


FIGURE 29
THE BELLINI-TOSI SYSTEM

large number of turns, reproduce the external electro-magnetic field in greater intensity. If a small rotating coil (the search coil), complete with pointer and dial, is now fixed in the centre of the two internal coils, a loop bearing may be taken in the ordinary manner. Sense is found by the aid of a separate sense aerial which is usually suspended from an insulator at the apex of the external triangular loops.

THE MARCONI-ADCOCK SYSTEM

The Bellini-Tosi aerial system has the serious disadvantage of being subject to night effect, which may produce errors of such magnitude as to make bearings useless. This weakness has been nearly eliminated in modern installations by the use of the Marconi-Adcock aerial, which has no horizontal members liable to be affected by the reflected sky wave. The triangular loops are replaced by U-shaped aerials, of which the horizontal portions are buried in the earth and are screened from downcoming waves (Fig. 30).

The actual wireless masts serve as aerials and are mounted on large insulators. The

horizontal cables which connect them to the radio goniometer are insulated and then pass through metal screening pipes which are well earthed by being buried some six

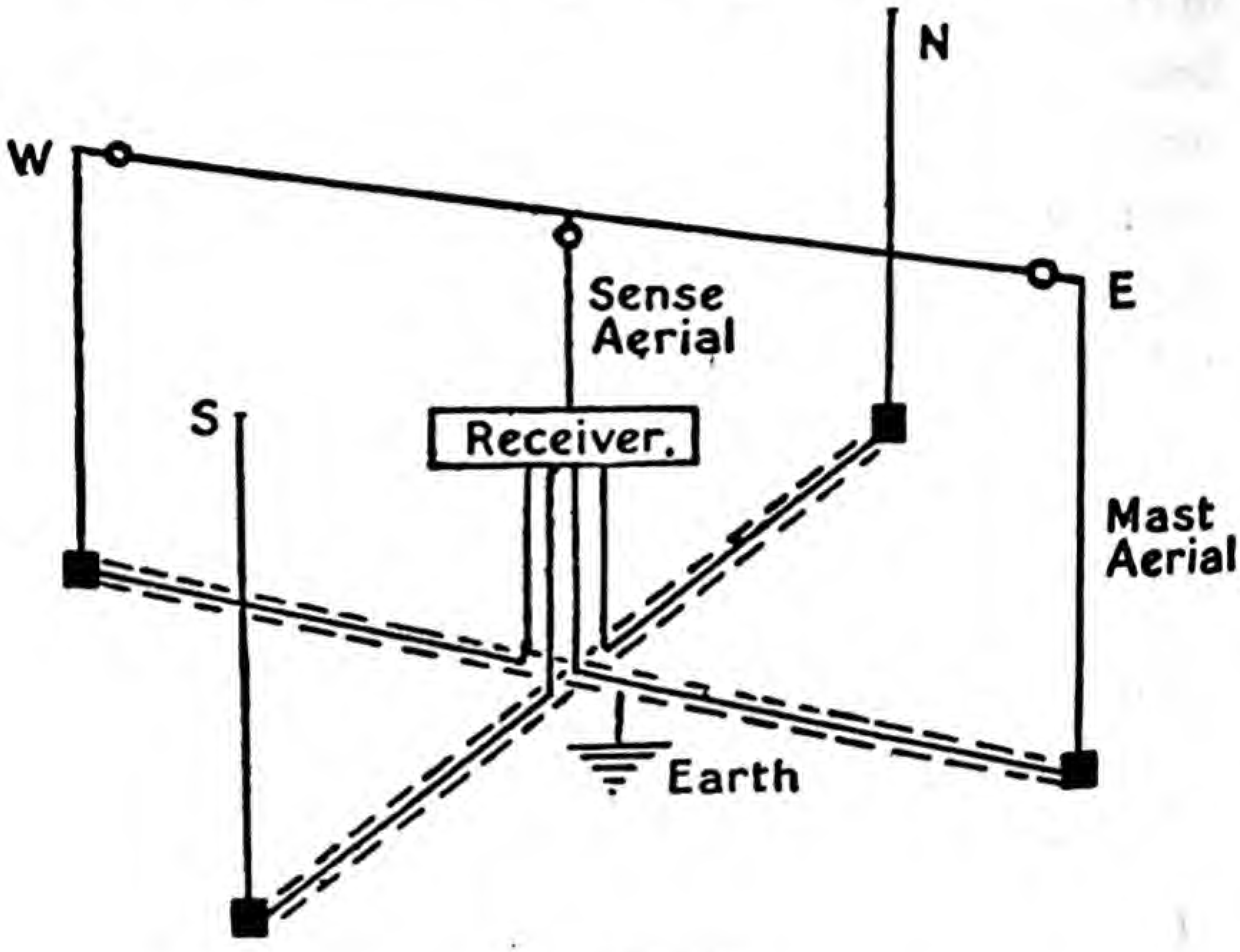


FIGURE 30
MARCONI-ADCOCK AERIAL SYSTEM

feet underground. The sense aerial is hung from an insulated stay passing from mast to mast.

Ground D/F stations are affected by coastal refraction if situated near the coast, but are able to calibrate the errors to some extent, and to make allowances for them.

Speed of plotting can be increased by the use of gnomonic maps. On these maps wireless bearings can be plotted as straight lines, but as the projection does not give bearings accurately from all points, a distorted compass-rose which compensates for any inaccuracies is drawn at the position of each station. Bearings can then be laid off direct.

Owing to the proficiency obtained by constant practice, the operators at ground D/F stations are able to judge the quality of bearings and can state with confidence whether they are first, second or third class. If second- or third-class bearings are given, an attempt is usually made to get a first-class bearing later.

PLOTTING

It sometimes happens that a navigator cannot obtain a fix from ground stations, but can obtain one or more bearings. The method of plotting these bearings depends on the type of map to be used and the distance of the aircraft from the ground station. Short range bearings may be laid off without correction from the position of the ground station, irrespective of the type of map. Medium range bearings can be laid off in

a similar manner, on all maps other than Mercator's. If a Mercator's map or chart is to be used, then medium range bearings are corrected for conversion angle which, once again, must be applied towards the equator. The corrected bearing is then laid off relative to the meridian of the ground station.

On maps other than Mercator's, long range bearings may be laid off without correction, as a straight line on these maps represents a great circle with sufficient accuracy for this purpose. When, however, long range bearings are to be laid off on a Mercator's chart, special measures must be taken or large errors may be introduced owing to miscalculation of the dead-reckoning position of the aircraft. Let us assume, then, an aircraft whose *approximate* dead-reckoning position is in latitude 62 N., longitude 20° E., bears 089° from a ground station in latitude 63° N., longitude 05° E. The conversion angle for a middle latitude of 62½° N., and a change of longitude of 15°, is approximately 7°.

Wireless Bearing	089°
Conversion Angle	7°
Mercatorial Bearing	096°

In Fig. 31 it will be seen that the Mercatorial or rhumb line bearing of 096° has been laid off from G, the position of the ground station. This line cuts the dead-

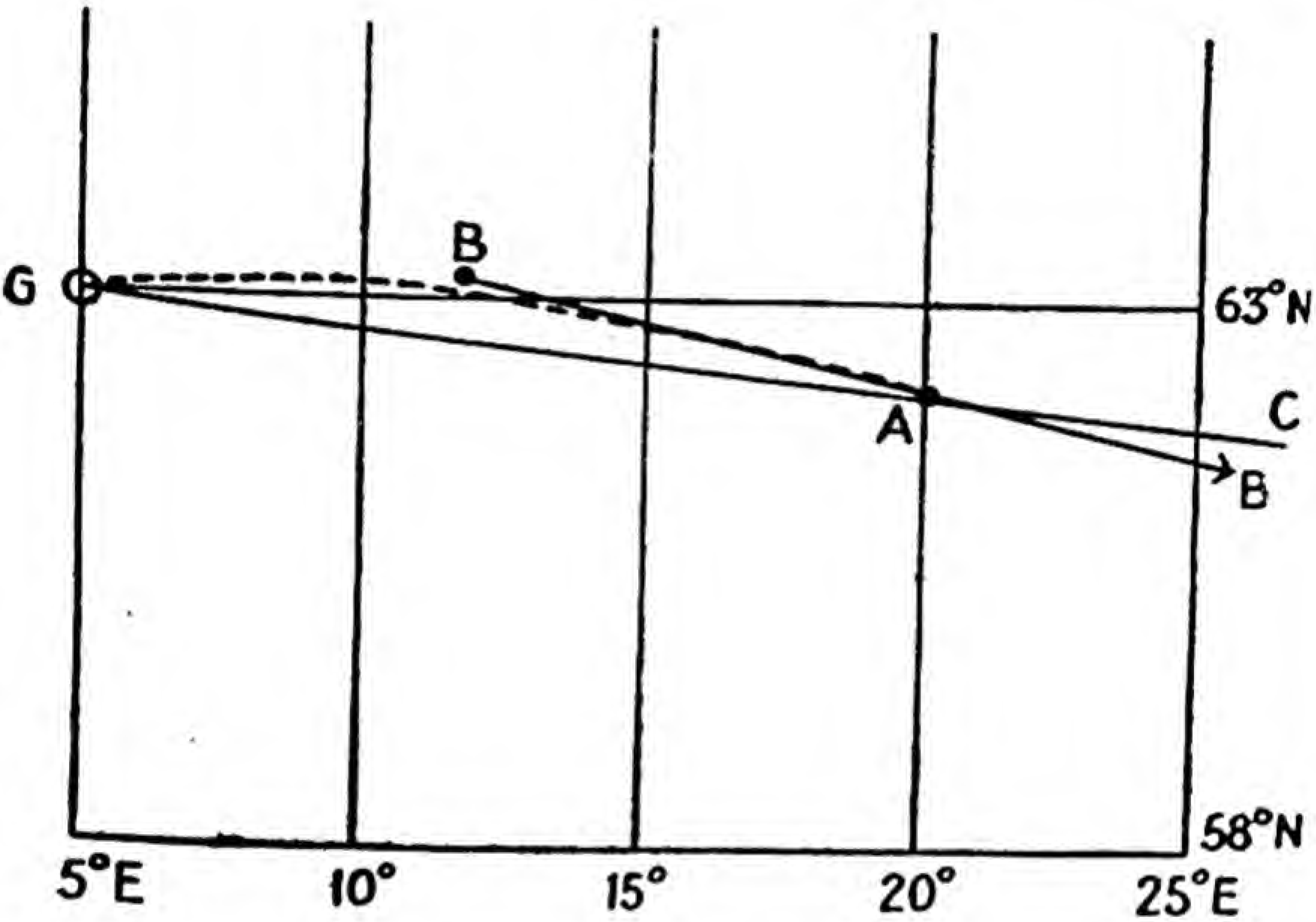


FIGURE 31
TANGENT OF GREAT CIRCLE

reckoning longitude at A, which will be the position of the aircraft if the D/R longitude, and hence the conversion angle, are correct. (Note.—The error of D/R latitude is less important.)

It is more than probable that these factors are in error, and it is therefore advisable to

use as a position line a tangent to the great circle bearing. We know that the conversion angle is the angle between the rhumb line bearing and the great circle bearing, and that the great circle bearing is always on the polar side of the rhumb line, so if the conversion angle is laid off from A towards the pole it will give a tangent to the great circle bearing, BB. The aircraft must be situated somewhere on the great circle bearing, and a portion of the position line BB situated in the vicinity of the D/R position in a more accurate position line than the original mercatorial bearing GAC. This statement may be proved by calculating the conversion angle for two assumed longitudes and the same bearing.

Bearings should be plotted in the above manner if the conversion angle exceeds about 4°. This is only likely when working at long range in high latitudes, and when the bearing runs near the East-and-West. To get a good fix, it is necessary that the two bearings used should be at a fairly large angle. It follows, therefore, that if one bearing is near East and West, the other will be nearer North and South, and the conversion

angle for the latter will be small, owing to the small change of longitude involved. Hence it will only be necessary to apply a tangent to the great circle bearing for one of the two bearings.

CHAPTER VI

Route Markers and Approach Beacons

In many parts of the world the navigation of aircraft has been greatly simplified by the establishment of an elaborate system of track indicating radio-electric beacons, usually known as route markers or equi-signal beacons. With their aid, any aircraft equipped with a receiving set can pass from beacon to beacon in the same way as a coasting steamer can pass from lighthouse to lighthouse. In the territory of countries at war, this service has, of course, been discontinued, as the beacons would be of assistance to enemy aircraft. In some cases, their place has been taken by mobile beacons whose position and call sign are frequently changed and are known to friendly aircraft only. These beacons may be placed on a particular route, but they are most frequently used as a guide to an aerodrome. The beacon's range seldom exceeds 50–60 miles, but aircraft returning from a night flight of several hours' duration should have little difficulty

in getting within that distance of the aerodrome by other methods of navigation.

Most beacons consist of two fixed loops set at right-angles to each other; each loop is energized independently and the resulting radiation gives a figure-of-eight polar diagram for the loop similar to that of a loop receiver. In other words, the signal strength is greatest in the plane of the loop and is zero at right-angles to it. In Fig. 32 the two loops are represented in the centre by AA and NN, and their greatest volume will be heard at the outer positions A and N. Now, each loop transmits a particular letter in Morse, such as A or N. The timing of the transmitter is such that the A from one loop interlocks with the N of the other, so that if both can be heard in equal volume at the same time a continuous dash is the result. In Fig. 32 it will be seen that the sectors marked "Dash" are mid-way between the A and N quadrants. In these sectors both loops will be heard at equal volume. In between the sectors, one letter will predominate and will be much louder than the other. Let us suppose that an aircraft B has picked up the call sign of the beacon, which is sent out from time to time, and then hears

a series of loud N's and weak A's. The aircraft is heading 295°, and after continuing in this direction for some minutes it is found

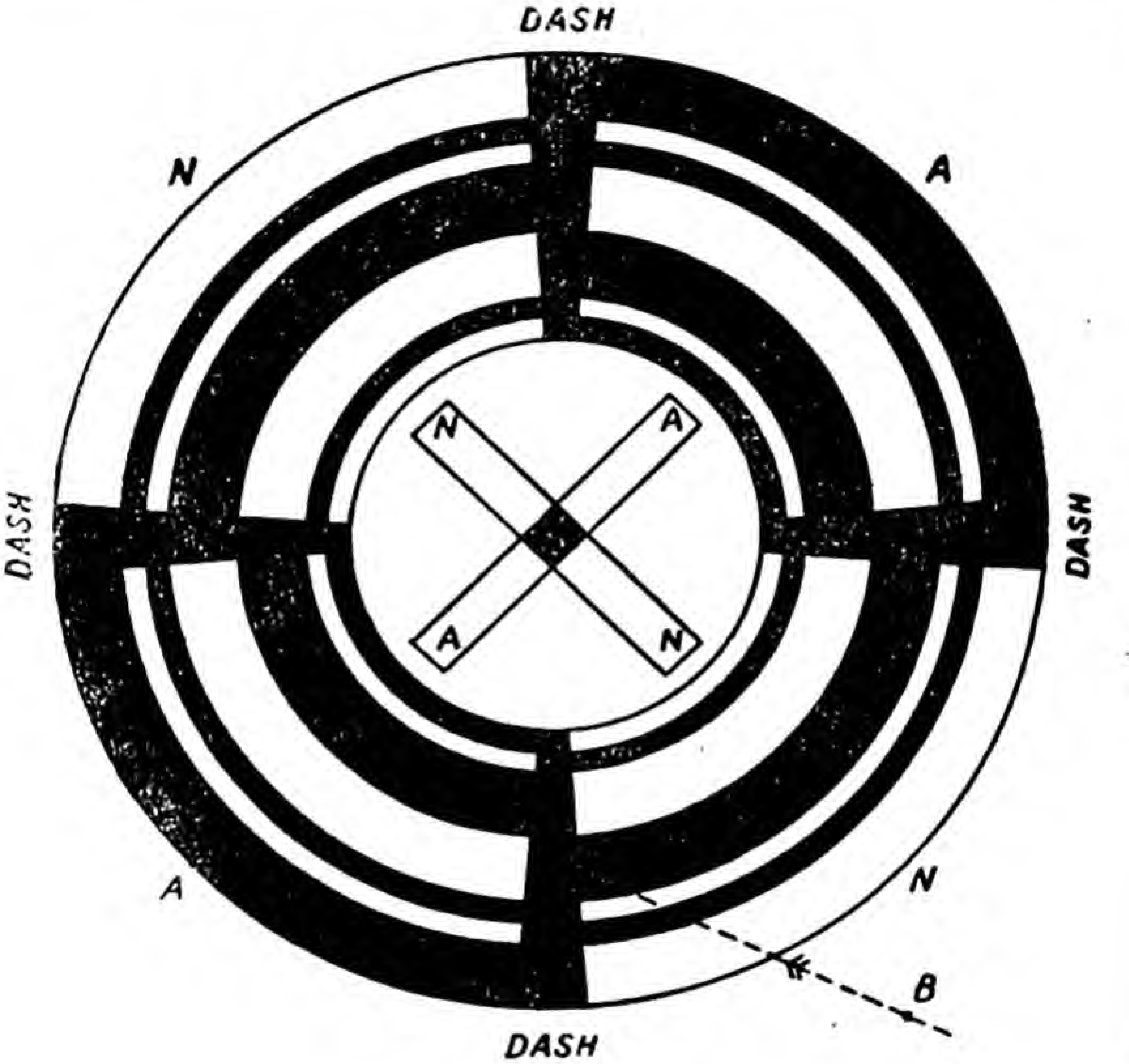


FIGURE 32
DIRECTIONAL BEACON—DIAGRAM

that the N's become weaker and the A's louder. When the strength of the two letters tends to equalize, it proves that the aircraft is flying towards the nearest beam, and if

the same course is maintained the A and N signals will eventually merge into the continuous dash. The aircraft must then be turned in order to remain in the beam.

Knowledge of the characteristics of the beacon and the course of the aircraft should enable the navigator or pilot to decide on which side of the beacon he is, and therefore which way to turn. Should the aircraft continue to fly along the beam, a big increase in signal strength will be heard just before and just after passing over the beacon. Directly above the beacon, there is a "cone of silence" in which no signals will be heard. Beacons are subject to bending of the wave path by mountains or coastlines, and to certain temporary errors at sunset and sunrise.

THE CATHODE RAY

The cathode ray tube is a comparatively new development, and one which, before the war, was largely associated with television. In the ordinary television set, the luminous glass screen upon which the pictures appear is the end of a cathode-ray tube.

In another form, it was known as the

cathode ray oscilloscope, and was used in factories engaged in manufacturing radio receivers, for aligning the various stages of the receivers. Service engineers also used a portable oscillograph for fault detecting.

Since the beginning of the war, the main use of the cathode-ray tube has been in connection with direction-finding wireless, or radio location. The apparatus used for this purpose is, of course, on the secret list, but the ordinary commercial cathode-ray tube is not, and it is therefore proposed to give a brief description of it.

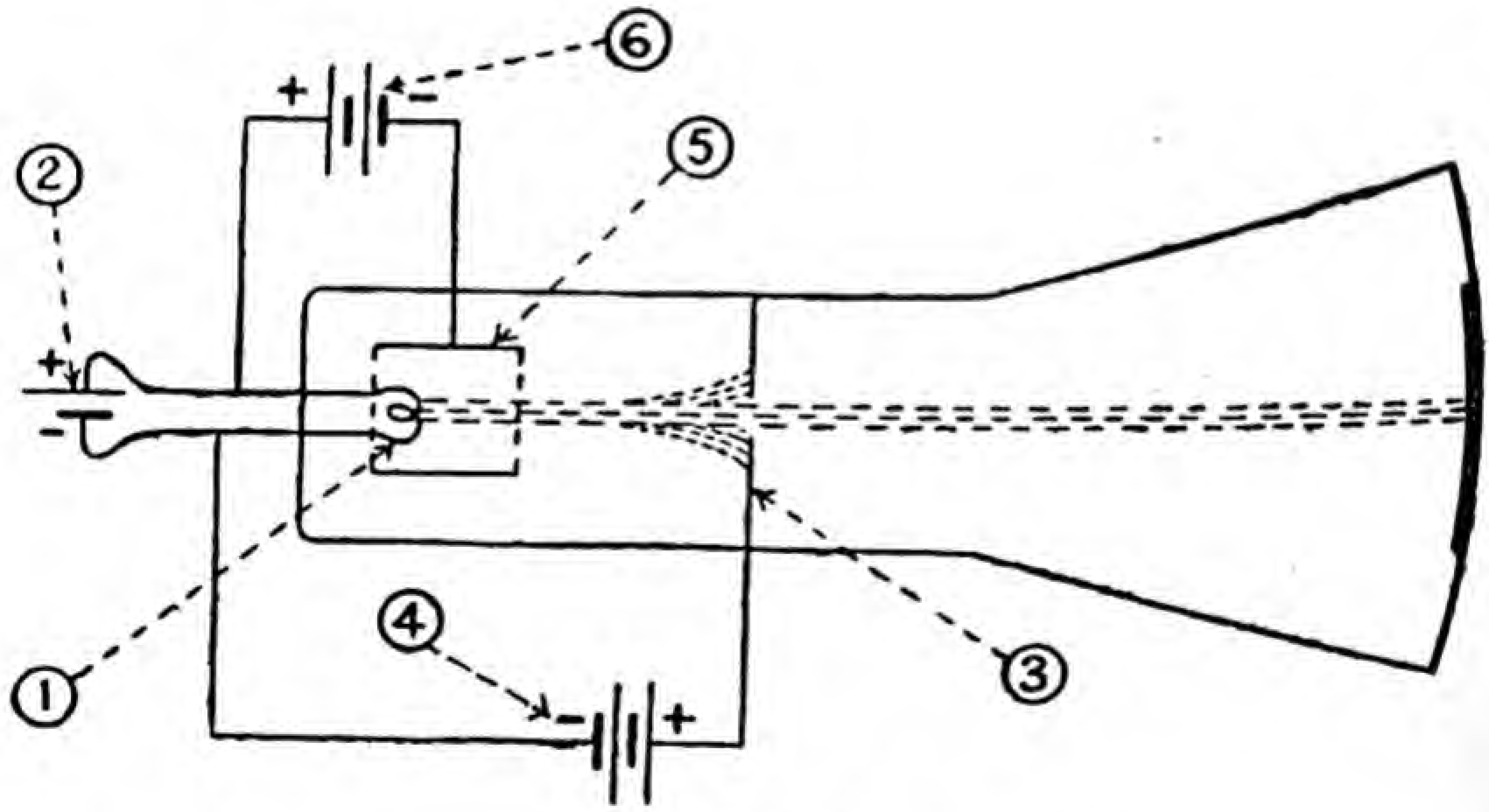


FIGURE 33
A SIMPLE CATHODE RAY TUBE

Fig. 33 shows diagrammatically a simple cathode-ray tube. It is a form of thermionic

valve, and has a filament (1) which is heated by its own battery, (2) or other source of supply. This filament is called the cathode. The cathode is made of a metal which, when heated, emits a stream of electrons. Further up the tube there is a plate (3) which is maintained at positive potential relative to the cathode, by the battery (4). This plate is called the anode.

The electrons emitted by the cathode are, of course, negative, and are attracted to the positive anode, so that a current is caused in the circuit containing the battery (4), the cathode (1), and the anode (3).

It will be seen that there is a small hole in the centre of the anode. Owing to the momentum acquired by the electrons, many of them pass through this hole and continue in a beam to the end of the tube. If the end of the tube is coated with certain chemicals, the electron stream will cause the chemicals to become fluorescent at the point of contact.

As the electrons are all negative, they have a repulsive effect on each other, so that the diameter of the electron beam at the point where it strikes the fluorescent screen is greater than its diameter when passing

through the hole in the anode. It is desirable that the electron beam should be focussed to produce a small bright spot of light, and there are two methods of achieving this aim.

The first method takes the form of the "soft" cathode-ray tube. In Fig. 33, it will be seen that there is a small cylinder just in front of the cathode (5). This is called the Wehnelt cylinder, and it is kept at negative potential by the battery (6), so that the outer electrons in the electron beam are repulsed, owing to the similarity of potential, and are therefore concentrated into a narrow beam. Less electrons pass to the anode, and more pass through the hole.

The actual focussing of this beam is done by filling the tube with an inert gas, which, when subjected to the electron stream, becomes ionised, and of positive potential. The positive ions attract the negative electrons of the beam, and tend to draw them into a fine, concentrated stream.

In the "hard" cathode-ray tube, the tube is evacuated, but has the ordinary cathode, Wehnelt cylinder, and anode as before.

In addition, it has a second or third anode, arranged further up the tube, and kept at positive potential. The potential on

these anodes is adjustable, and by this means the electron beam may be focussed on the fluorescent screen.

Having produced the small spot of light, the next step is to make it indicate direction.

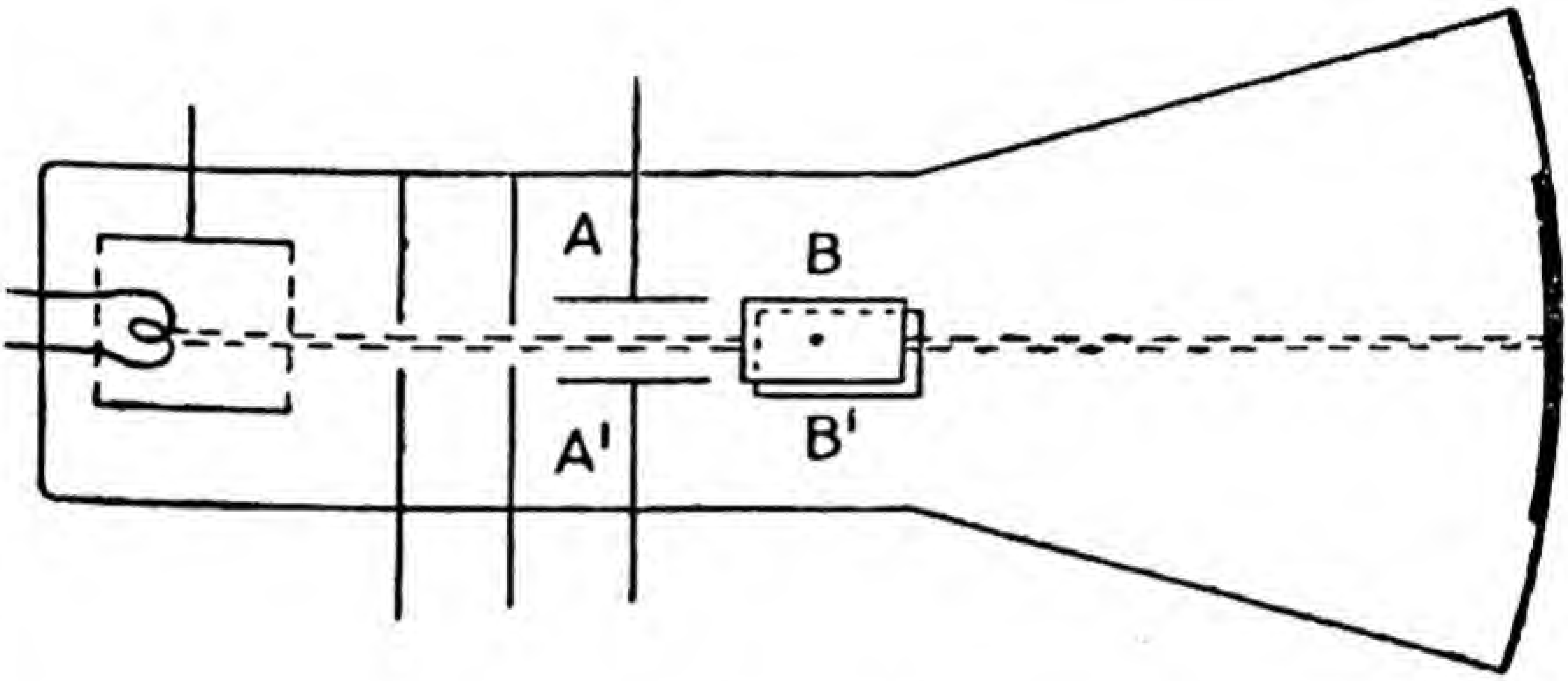


FIGURE 34
DIRECTION-FINDING CATHODE RAY TUBE

In Fig. 34 it will be seen that two parallel plates A–A¹ have been introduced into the tube, with a further pair B–B¹ at right angles to them, a little further up the tube. These are called lining-up plates, and the electron beam passes between them.

If the lining-up plates are now connected to external loop aerials of the Marconi–Adcock pattern, an electrostatic field will be produced in the tube, and will have the effect of diverting the electron beam in a

certain direction, according to the direction of the wireless wave being received in the external aerials.

If the end of the cathode-ray tube is engraved with a compass dial, the position of the spot of light will enable the bearing to be seen at a glance. In order that there may be no doubt as to whether it is the bearing or its reciprocal, a sense aerial is cut-in to the circuit by means of a spring-loaded switch, and has the effect of blurring-out the reciprocal.

The advantage of the cathode-ray system of direction-finding is its speed of operation, range, sensitivity, and versatility.

CONCLUSION

The apparatus described in the foregoing chapters is that which is in general use, and it is not suggested that there are not numerous other types of equipment worth studying. Those who wish to pursue the subject further cannot do better than to read the *Admiralty Manual of Wireless Telegraphy*, Keen's *Wireless Direction Finding*, and *Through the Overcast*, by Assen Jordanoff.

GEORGE ALLEN & UNWIN LTD
London: 40 Museum Street, W.C.1
Cape Town: 58–60 Long Street
Sydney, N.S.W.: 65 York Street
Toronto: 91 Wellington Street West
Bombay: 15 Graham Road, Ballard Estate
Wellington, N.Z.: 8 Kings Crescent, Lower Hutt

OBSERVERS BOOKS

2*s*. 6*d*. *net each*

No. 1. The Observer's Book on Maps, Charts and Projections

by W. J. D. Allan *and* William Alexander

This book is written by two instructors from one of our largest training schools who have had experience in training hundreds of observers and pilots for their examinations, and is in reply to continual requests from their pupils to recommend a small book on maps and charts giving the information needed for their examinations.

"One of the clearest, most straight-forward and easy-to-understand descriptions of maps, charts and projections that have been written."—*Aeroplane*

"It can be recommended as a trustworthy guide."—*Aeronautics*

Sixth Impression

No. 2. The Observer's Book on Dead Reckoning Navigation

by W. J. D. Allan *and* William Alexander

This second handbook covers all forms of Dead Reckoning Navigation, a subject with which every navigator should be thoroughly at home. In recent years the increasing speed of aircraft has involved the introduction of a new technique, and this modern practice is embodied in this volume. The problems are clearly explained, and illustrated by a large number of line drawings, and examples for exercise are given at the end of the book.

Sixth Impression

Nos. 3, 4, 5 and 9. The Observer's Book on Astro-Navigation

by Francis Chichester

(Parts one, two and three 2s. 6d. net each. Part four, advanced Astro-Navigation, 4s. 6d. net)

The object of these little books is to help an observer learn sufficient astro-navigation for position-fixing in the air. There are not enough instructors to teach every observer astro-navigation, nor can observers be spared for a long course. But an intelligent man, who already knows his Dead Reckoning navigation, can teach himself astro-navigation without using up much of an instructor's time. In fact, some navigators have taught themselves the art without any outside help.

Secondly, the books are intended to serve as a refresher for the man who has already learnt astro-navigation. It frequently happens that a navigator is suddenly called on to fix his position by the stars when he has not touched a sextant for three months. In such cases it is invaluable to refer to a step-by-step explanation of the necessary procedure. Often the most brilliant mathematicians are unable to remember methods or formulae.

Only the methods in general practice to-day are described, and the author has tried to cut down explanation to a minimum; but it is felt that this minimum must include the reason for performing each act. The author therefore sets out exactly what must be done to fix position in an aircraft by astro-navigation, and why.

The author has unusual qualifications for writing on his subject. He has navigated a light seaplane—relying completely on solar observations—first to one small island and later to another. He was probably the first to do such a thing when flying alone, and it is doubtful if anyone else has attempted it since. He was awarded the Johnston Memorial Trophy for astro-navigation, the highest recognition attainable for navigational ability.

No. 7. Meteorology

by W. J. D. Allan *and* William Alexander

No. 8. Aircraft Instruments

by W. J. D. Allan

No. 10. Practical Mathematics

by P. H. Robinson (*Double Vol. 4s. 6d. net*)

No. 11. Planisphere of Air Navigation Stars

by Francis Chichester

A HISTORY OF THE AIR MINISTRY

by C. G. Grey

Demy 8vo. 10*s.* 6*d. net*

"Presented plainly, cogently and with no sops to existing or past Cerberuses."—*Sphere*

This book is an informative history of how the Air Ministry came into being during the War of 1914–18, by separating the Royal Naval Air Service from the Navy and separating the Royal Flying Corps from the Army and turning them into the Royal Air Force, with a Ministry of its own, which ranks with but after the Admiralty and the War Office. Recording how the Air Ministry was brought into being includes a short history of the two Flying Services, and the lines along which they developed independently until they were fused together. That incidentally involves a brief study of the development of air strategy and tactics and some illuminating examples of the psychology of the Services.

The book is also an explanation of the organization of the Air Ministry and a review of the work which is done by the numerous departments into which it is divided, and a record of what the Air Ministry has done since it came into being.

C. G. Grey founded the *Aeroplane* in 1911 and edited it until 1939. He has edited *Jane's All the World Aircraft* since 1916.